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A Review on Light Shelf Design by Machine Learning to Predict Daylighting Requirements

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Abstract- Climate change is a problem that requires effective solutions. Much research on this subject is now being undertaken because of the recent rise in the energy consumption of lighting. Sustainable strategies serve as excellent examples of energy efficiency in the building sector. Daylight simulations are time-consuming and computationally expensive. Predictive lighting tools combined with predictive models built on machine learning algorithms (MLAs) can improve their output by using neural network algorithms to make decisions early in the design process, which takes a long time when simulation operations are based on evolutionary algorithms. The investigatory methodology employs an analytical framework in which machine learning algorithms are used to configure the geometric parameters of a light shelf. This configuration is then examined in terms of its influence on daylight metrics. This paper showed how combining artificial intelligence techniques with evolutionary algorithms can improve the design of light shelf parameters to meet daylighting requirements. The main results of the study reveal that most office buildings, specifically 54.5%, prefer using a light shelf. In addition, among the commonly experienced climate types, the Mediterranean climate is particularly prevalent, accounting for 36.4%. The evaluation of the simulation tools involved the use of a parametric program that incorporated all significant daylighting metrics as output parameters. Of these metrics, the Useful Daylight Index (UDI) stands out as the most notable, and it is expected to have a significant influence on shaping future light shelf designs using machine learning concepts.

Keywords Daylighting, light shelf, machine learning, artificial neural network.

Nomenclature

Abbreviation	Description
ML	Machine Learning
ANNs	Artificial Neural Networks
WPI	Work Plane Illumination
SDA	Spatial Daylight Autonomy
$ASE_{1000, 250}$	Annual Sunlight Exposure
GP	Gaussian process

1. Introduction

In recent years, many academics focused on how well new technologies can increase the amount of natural light inside buildings. A light shelf is a natural lighting system whose use has been cited in numerous studies as an effective way to minimize lighting energy consumption [1]. To regulate daylight, it is typically placed in the upper part of windows above eye level and used in combination with shading [2]. Light shelves, as daylighting systems designed to reduce lighting consumption, have been studied as the subject most of investigations [3] and have created a pleasing environment that gives its occupants visual comfort [4]. Warrier and

Raphael have also pointed out that the main shortcomings of the existing models for assessing how well light shelves improve daylight performance have been recognized [5]. They noted that the potential for stronger lighting close to the window with horizontal light shelves is likely to increase the risk of glare. In sustainable building design, increasing energy efficiency is viewed as the most effective approach to meeting and overcoming continuously rising energy needs in many emerging and developed economies [6, 7].

Since smart indoor lighting has become so popular in recent years, it is now an essential part of any modern building [8]. Integrating daylight control systems with artificial lighting systems guarantees high energy efficiency in compliance with ideal design concepts and technological requirements [8]. When selecting automation and control features for a building, it is important to examine how these elements affect the efficiency of the facility and its capacity to provide indoor comfort [9].

Light shelf mounting height, geometry, building orientation, location, material, and the environmental conditions that affect the light shelf [10] are only a few of the factors that can determine how well light shelves operate in various geometrical configurations [11]. Given that the effectiveness of light shelves is contingent upon a range of factors such as their configuration, material composition, dimensions, and the inclination angles of both their internal and external elements, it is imperative to meticulously devise optimal parameters during the initial design phase [12]. Several studies have shown that variables of light shelf geometry, including shelf dimensions and shelf rotation angle, affect daylighting and visual comfort in the ambient environment [2]. They also discovered that tiltable light shelves may improve lighting in offices [10]. According to [13], changing the geometry of the ceiling can enhance the performance of the light shelf. Littlefair [14] discovered that light shelves can help a room's daylight uniformity and offer some solar shade, but they have little effect on the amount of light that enters the room at the rear .They found that light shelves can be used to increase illuminance in office rooms [10]. Kontadakis [15] found that light shelves are a popular solution for daylighting because they can be used to control light in a space, improve daylight uniformity, offer shade, and improve daylighting in a space with a sloped ceiling. Noshin [16] found that light shelves can be used to increase the illuminance of a space. This paper argues that using IT technology may reduce energy use and that machine learning can be used for many things related to light, such as understanding and designing light-harvesting devices [17], designing lighting systems, and optimizing design decisions [18]. However, none of the studies directly answer the question, "Why use machine learning ideas when making light shelves?" Hence, we can only assume that the use of machine learning in light shelf design is done to speed up forecasts of the performance of natural and artificial lighting. Predictions of response variables at a future time or under a given set of parameters are now possible thanks to machine learning methods. These methods use recent data to verify and link response and cause variables, described by Horvitz and Mulligan, "Machine Learning: Trends, Perspectives, and Prospects."[19]. While simulation software can take a long time to create, learned models can be used in minutes [20].

Researchers and practitioners should use long-term daylighting models and simulations to foresee the efficacy of their design strategies and decisions [21]. Nourkojouri found that the accuracy of machine learning predictions is estimated at 97% on average, which suggests that machine learning is a reliable tool [22]. The various ML tools use various algorithms, most of which are derived from ray tracing or radiosity techniques [23], and are validated by the Radiance-based software. For example, the back-propagation concept of artificial neural networks (ANNs) has been used in the field of architectural lighting [21], where it can analyze and process large data sets and provide the illuminance of a point as an output [9]. For more complex design light shelf characteristics and other daylight concerns, such as thermal comfort, visual comfort, and energy savings, Ahmed recommends using this optimization method. The design challenge for the light shelf parameters can be optimized using validation and sensitivity analysis, which can also be used to determine the design factors that are most significant [24]. Minimizing a building's energy usage can be accomplished through the development of machine learning algorithms for use in the dynamic, predictive management of indoor daylight illuminance [25]. Machine Learning (ML) methods are used to evaluate daylighting performance in buildings during the early design stage.

2. Research Aims and Methodology

By employing natural light to illuminate buildings instead of artificial lighting, substantial energy may be saved, which in turn lowers the need for heating and cooling [26]. The objective of this study is to enhance the efficacy of the light shelf as a daylighting system through the provision of a dependable analytical approach, findings with broad applicability, and viable design solutions. In-depth evaluations of the available illuminance levels (such as how evenly the illuminance is dispersed across the room) are sometimes difficult to achieve using conventional analytical methods [25], and this can be achieved by predicting daylight autonomy metrics using machine learning [7]. To forecast the output targets of the light shelf design model, a regression-type problem was solved theoretically. The literature study found that 87% of the ML-based daylight field investigations were regression issues but were not relevant to the design of light shelves [22]. The study asks the following questions:

- Why use a light shelf design for daylighting?
- Why use the machine learning concept in light shelf design?

These findings suggest that machine learning is a useful tool for various purposes related to daylight prediction and may be particularly useful for light shelf design. However, more research is required to confirm this. With less reliance on electric illumination, machine learning may also be used to provide visual comfort to occupants. However, further study is required to support these assertions. To improve the study's literature and incorporate a categorization of the earlier studies, the most current papers on the Light shelf were studied and considered for the research's objectives. All proposed publications are submitted to the subject framework of the full review, which is organized into the following sections:

- Section 1: An introduction to daylighting, light shelves, and machine learning.
- Section 2: Highlights of the Research Aims and Methodology.
- Section 3: Review of research on the use of the light shelf with daylight and machine learning.
- Section 4: Results of the survey and a light shelf components are described.
- Section 5: Discusses light shelf design using the ML tool.
- Section 6: Conclusion.

3. Literature Review

Soler and Oteiza [27] studied an office model at Madrid (40.4 ° N, 4.4 ° W) with a fixed light shelf designed as internal and external parts of rectangular openings facing south, a reflectance material was 91% (aluminum painted), a mean hourly illuminance as a metric of day lighting's measurement on the points closest to the walls opposite the openings for days with clear skies, and the dependence on solar elevation. They reported that the light shelf provided greater consistency for the illuminance values than the reference model at the "worst" lighted location for which measurements are available, situated at a distance of 50 cm from the aperture. Soler et al. [28] determined how to make the previous light shelf parameters work with a high ceiling reflectance. In addition, dependance on solar elevation and azimuth factors. The results shown were produced using a light shelf and ceiling model reflectivity with specular restrictions. In their investigation, Claros et al. [29] conducted a comparative analysis involving two light shelves and an overhang constructed using real-world reflectance materials coupled with methacrylate, as well as mirror-type light shelves and a model featuring an overhang. Both a light shelf and an overhang were found to offer equivalent solar protection over a year. However, a quantitative assessment of each alternative was conducted by analyzing the measured illumination availability metric to provide a more precise evaluation. The light shelves were found to perform better than the overhang model.

In a test room in Madrid, Spain, Claros et al. [30] proposed four light shelf variables that serve as shading devices and daylighting systems. The light shelves were constructed from untreated aluminum that underwent a three-fold coating process, involving white matte paint, white opaque methacrylate, mirrored surfaces, and raw aluminium. The following models were used for the measurements: walls, doors, and ceiling painted white matte; painted for actual reflectance values; and white painted matte. The measurements were conducted over three years, with one of the three models employed each year. During the intermediate months of the year, the light shelf made from methacrylate showed better performance than the light shelf made from mirrors. However, for three months at the end of the year, the mirror light shelf performed better, than its methacrylate counterpart. The mean hourly illuminance values are measured as metrics. The effect of ceiling geometries on the performance of light shelves in a sizable space situated in subtropical temperature regions was examined by Freewan et al. [13] in a test room at Irbid, Jordan. Changing the geometry of the ceiling can improve the performance of the light shelf. In comparison to spaces featuring traditional horizontal ceilings, the rear portion of the room exhibited elevated illumination levels, whereas the front area near the window experienced a reduction in illuminance. Concerning the uniformity of illuminance under constant light shelf configurations, the most favorable ceiling configuration featured curvature in both the front and rear sections of the room. Raphael [31] presented a case analysis of a tropical region office in Singapore. This investigation focused on the geometric attributes of the light shelf, including the dynamic adjustment of its external angle, the dimensions of its internal section, its height, and the presence of a highly reflective ceiling.

These parameters were actively calculated in real time to mitigate the energy consumption associated with artificial lighting. Significant energy savings are possible with building automation and control. They found an increase in the daylighting levels in the interior of the room. In comparison to static light shelves, the adaptable light shelf design with a rotating external section and movable internal part results in a 12% net energy reduction. Work plane illumination (WPI) quantity and uniformity were used by Lim et al. [32] to analyze a case study of a workplace in Johor, Malaysia [Tropical climate] and to determine the daylighting performance of light shelves for visual comfort. Instead of taking the façade orientations into account, they created a light shelf by adapting to changing sky conditions. The analysis involved the calculation of output metrics, specifically the daylight and uniformity ratios of work-plane illumination (WPI). The highest improvement in WPI in the deep room was 24.87%. A dynamic internal light shelf was suggested by Lim et al. [33] to offer the best daylighting performance for various sky conditions, hours, months, and orientations under a tropical sky. This study demonstrated the suboptimal quality of daylighting in tall office buildings lacking shading devices, resulting in an average illuminance of 11,193 lux and a uniformity ratio below 0.1. Among the evaluated configurations, light shelves featuring three internal components and those with two internal components demonstrated the most favorable performance when exposed to intermediate sky conditions. Conversely, configurations with only one internal component yielded the best results under overcast sky conditions.

Meresi [4] conducted an investigation involving a standard classroom located in Athens, Greece, to enhance the distribution of daylight within the room. The chosen system for this study was installed on south-facing windows and consisted of a light shelf designed to provide shading and redirect light, along with semi-transparent adjustable external blinds that could be customized to meet the occupants' shading preferences. Parameters such as the width of the light shelf, its mounting height, tilt angle, and reflectance index were meticulously considered because they played a crucial role in augmenting daylight performance. When used in combination with semi-transparent, moveable exterior blinds, a light shelf can maximize the use of natural light in classrooms by providing shade and evenly distributing light. The daylight efficiency and visual comfort of Iranian educational rooms were studied by Moazzeni et al. [2] using data on light shelf factors such as size, rotation angle, and orientation. This annual analysis is based on climate information from daylight simulation software. The dimensions and placement of the light shelf, especially when facing south, have a substantial influence on the distribution of daylight and the level of visual comfort. Increased light shelf dimensions at the southern orientation lead to an increase in the workplane's region with adequate daylight levels of 2% - 40% and a decrease in unpleasant glare. Lee et al. [34] suggested a perforated shelf to reduce the impact of wind pressure on the upper levels of high-rise buildings. The main variable in their studies was the vent ratios on light shelf patterns. This suggests that the width of the perforated light shelf may be changed to account for wind pressure and other features of the light installation location, thereby increasing the energy-saving performance of the lighting.

Lee et al. [1] designed a mobile light shelf system equipped with location-aware technology for performance evaluation. To assess the energy-saving capabilities of this innovation, a life-size experimental platform was created. The proposed light shelf was shown to be adaptable to external environmental conditions and occupant positions by controlling the light shelf's axis, module angle, and reflector. More research is necessary to overcome this problem because it is considered that this system is less efficient than earlier light-shelf systems at increasing the indoor uniformity ratio of lighting. Youssef et al. [35] introduced a window design with a minimal external wall-opening area tailored to the specific context of Sinai, Egypt. The optimization of daylighting performance in this design is contingent on the precise placement of the light shelf, particularly in response to overcast sky conditions. Various attributes of the light shelf, including its shape (concave, rectangular, convex), dimensions (width, depth, height), and material composition, were explored. The objective was to attain a balanced distribution of indoor environmental daylighting, with a ratio of (1: 0.30: 0.10), to ensure visual comfort for occupants. The metrics employed for assessment included illuminance levels and daylight glare probability.

Berardi et al. [36] analyzed the advantages of light shelves in improving the available illumination levels within office buildings in Toronto, with useful daylight illumination as the key metric. They studied the impact of various fixed parameters of light shelves, such as window wall ratios, window shapes, facade orientations, and external obstructions. The study revealed that light shelves significantly enhance useful daylight illumination, particularly within the first 6 meters from the windows, while also promoting illumination uniformity, particularly when installed on south-oriented facades. Mangkuto et al. [37] conducted a study to improve the use of daylight by introducing lighting in an open-plan examination area at a dental hospital in Bandung, Indonesia. They employed a genetic algorithm to optimize the parametric design of light shelves, considering factors such as external and internal widths, external tilt angles, and the secularity of the light shelves. Maximize spatial daylight autonomy (SDA) and minimize annual sunlight exposure ($ASE_{1000,\ 250}$) in the room as output metrics. The optimized values for the west and east façades are as follows: previous light shelf's variables. Both metrics satisfied the criteria of multi-objective optimization. Lee et al. [3] designed a wide-adjustable reflector light shelf and tested its efficacy on a test bed. The suggested light shelf system's reflector is modular, allowing for gradual length adjustments. The ideal width of the light shelf is determined by reducing energy use and improving the uniformity ratio, and the resultant ideal width varies with the season. The energy of lighting could be saved by more than 20% when the light shelf included fixed reflector widths rather than width-adjustable reflectors. The light shelf width varied depending on the season's lighting and uniformity ratio. According to the minimum lighting energy consumption, the length of the light shelf varied in each season. The amount of direct natural light entering the interior space is reduced because the light shelf widens during winter. In Addition, in winter, the solar altitude is low, and a reduction in the light shelf's dimensions assisted in lowering the energy of lighting. Further research is also necessary to address these restrictions on the proposed light shelf's economic performance and handle associated energy problems in the construction industry.

Lee [38] proposed the integration of a light shelf with solar cells in South Korea, allowing for concurrent energy generation and lighting. The efficiency of this design depends on factors such as the surface area where solar modules are affixed, power generation capacity, and uniformity of illumination. Notably, the optimal angle for a light shelf without a photovoltaic module, which aims to minimize artificial lighting usage, differs from that for a light shelf with an integrated photovoltaic module, which aims to maximize power generation efficiency. The light shelf with a solar module was optimum covered 66.8%, and the optimum angle of adjustment required at the four seasons varied. They then developed it folding technology and solar modules to increase their energy efficiency [39]. Lee et al. [40] studied a movable curved light shelf to evaluate its effectiveness and optimal specifications. The tilted flat light shelf varied according to season's conditions and varied different optimum angles for a moveable, curving light shelf. According to these ideal criteria, a fixed-type curved light shelf can use 3.6% less energy than a mobile flat light shelf. They advised that the curved light shelf be considered as an efficient solution and that further research should be conducted to analyze numerous other elements. Ahmed et al. [24] evaluated office spaces to determine the efficacy of an optimization process for a light shelf system. This system involved the integration of a light shelf with a fully glazed facade and utilized dynamic daylight metrics within work-plane environments through the application of genetic optimization techniques. The objective was to assist architects in assessing daylighting energy considerations. The assessment was conducted under Malaysian sky conditions, encompassing two solar solstices

(June and December) and one equinox (March), and involved the evaluation of five distinct light shelf configurations.

The optimization findings show that there is much room for lighting improvement using the best design alternatives for light shelf parameters. To study the performance values of the best design, statistical analysis was performed. The results revealed that the regression analysis had high levels of reliability and varied levels of variance coefficients. Bahdad et al. [12] presented an energy-efficient and well-illuminated workplace achieved through optimization. This study delved into the application of multi-objective optimization techniques using non-dominated sorting genetic algorithms, which Excel file in providing optimal solutions for multiple concurrent design objectives. To simulate daylight, energy considerations, and optimization processes, parametric software tools such as Grasshopper, along with associated plugins such as Honeybee, Ladybug, and Octopus were employed in their investigation [41]. While the optimization for multiple objectives together proved to be a useful tool for investigating the trade-offs between the two conflicting purposes, the optimization focused on single objectives that demonstrated significant variations between daylight availability and energy efficiency.

4. Results

Overall, the results presented below show that using the light shelf as a shading devices in temperate/tropical climates is difficult because of excessive heat and glare. Widely used in office buildings, and educational and residential spaces. The importance of offices is related to energy consumption during daylight hours and the large size of the curtain wall system. The performance of the light shelf was measured from physical measurements to parametric simulation [program RHINO and Grasshopper], and validation of the results is shown in the appendix A. Machine learning was recently used to improve parametric simulation work such as the Pug plugin/Rhinoceros software.

The light shelf design in Table 1 affects all input parameters, including length, width, rotation angle, and material properties. The most important finding from our investigation into various modifications to the design of light shelves was that outdoor environmental conditions had a greater impact on inside daylight illuminance than indoor architectural design elements. The benefit of using machine learning is the simulation's computing time difference. Similar to traditional lighting simulations, the values predicted by ML tools are trustworthy for use in early design.

The artificial neural network's forecast is always processed using inputs from and outputs to the network design, and the accuracy of its calculations, geometrical complexity, and the processing power of each processing unit are determined by the time taken by the daylight simulation.

5. Discussion

The review results are discussed in the following subsections, which are structured in the same chronological order as the previous section: Scope of light shelf geometry, materials; variables and parameters of the light shelf, building type, and evaluation metrics; and machine learning concept.

5.1. Light Shelf Parameters Related to Daylighting Design

To make a light shelf, you need a good sense of geometry and the ability to predict how light will act on surfaces. One of the main goals of this paper was to attempt to find a way to determine whether the light shelf has been designed with the concept of machine learning before shown in Figure 1. These results both support and negate some of the hypotheses.

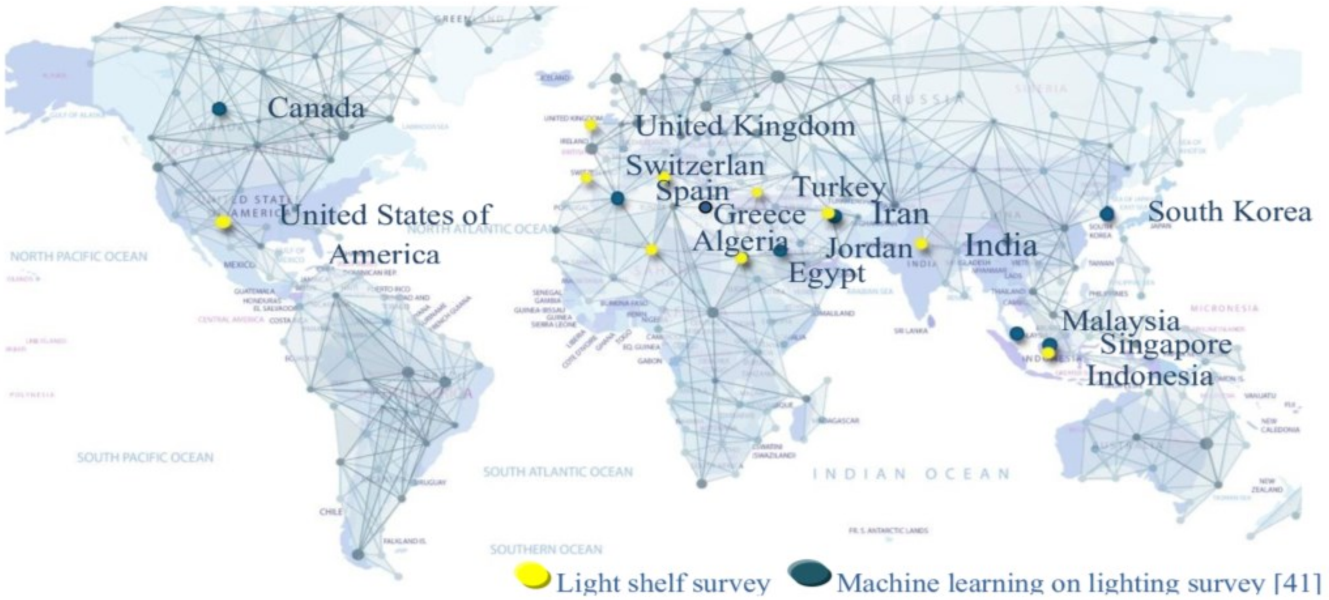
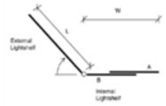
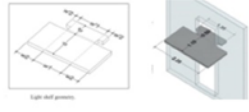
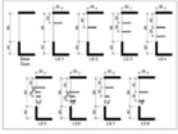
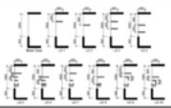
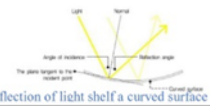
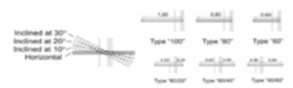
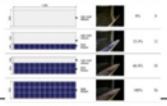
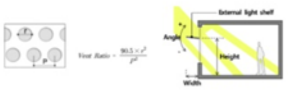
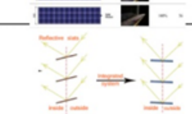
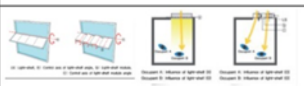
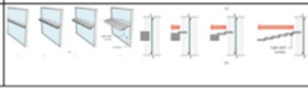
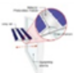


Fig. 1. World map showing geographical locations of light shelf survey [yellow] and machine learning on daylighting without light shelf concept [blue] in the reviewed studies.

Table 1. The majority of the concepts about light shelves were examined in the reviewed studies

Ref.	Year	Light Shelf Parameters	Figures	Ref.	Year	Light Shelf Parameters	Figures
[31]	2011	-External length -Tilted angle -Internal width -Internal Slide parts		[36]	2018	-W1:window width -W2:aspect width -D1:external depth -D2:internal depth	 Geometry Of Light Shelf
[32]	2015	-Internal width -Height from lintel -Number of internal parts -distance between parts		[46]	2019	- Inclined external angle/ rotating -Flat Shape -Fixed Width -Fixed Depth -Fixed Height	 Mechanism of Rotating of light shelf
[33]	2016	Internal Light Shelf configurations with L shape integrated		[40]	2019	-External -Incident angle -Reflective angle -Reflective surface	 Reflection of light shelf a curved surface
[4]	2016	-Internal width -External width -Inclined angle		[38]	2020	-Solar cells of light shelf a surface -Cover ratio /cells modules	
[34]	2016	-External length -Vent Ratio -Inclined angle -Internal Height		[45]	2020	-prismatic material of light shelf a surface - External +Internal	 Prismatic Material Of Light Shelf A
[1]	2016	-Rotated external parts -Inclined Angles -Location Awareness		[26]	2021	-Rotation slat -Machine learning algorithm - variable reflectance	
[3]	2018	-Folded external small parts		[39]	2022	-External movable photovoltaic modules + reflective slates	

It was predicted that light shelf geometry, materials, variables parameters of the light shelf, building types, and evaluation metrics would be applied in previous studies, but this turned out not to apply a machine learning concept to design it. The geometry of light shelf design is complex and requires an understanding of the physical properties of light and how it behaves in different environments.

Recent scientific papers have explored the geometry of light shelves, looking at ways to optimize the design to increase daylighting potential. These studies have looked at the optimal shape of the light shelf as well as the materials used to reflect and diffuse the light. The shape of the light shelf is a crucial element in its overall design and performance. The surface's angle and the shelf's length can be optimized to maximize the amount of daylight reflected and redirected into the building's interior.

The curvature of the light shelf's surface can be either convex or straight to achieve maximum efficiency in daylighting performance. Straight light shelves are easy to construct, but convex light shelves can provide better performance in terms of light reflection and scattering. Light shelves are an integral part of a building's daylighting system, and the materials used to construct them can significantly impact the daylighting requirements of the space. By carefully selecting the materials used in light shelf construction, architects can achieve optimal daylighting performance.

The most modern structures have intelligence built into them, whether it is through HVAC, lightning protection, or fire safety [6]. The smart lighting system is an integral part of any modern building.

Rapid adoption of smart indoor lighting has recently occurred [8]. The endeavor to create efficient control mechanisms and algorithms for intelligent indoor lighting systems is a complex and currently highly emphasized undertaking. Moreover, building control systems for automatic blinds and artificial lighting can use machine learning-based predictive models to increase energy efficiency [25] and integrate them with natural light tools such as shading devices. Light shelf design maximizes natural light while minimizing glare and heat gain in a variety of applications, such as residential and commercial buildings, museums, public spaces, and energy-efficient green buildings. The design process can be streamlined and validated early using daylight simulation methods [42]. Using computational simulation to include luminance-based metrics in architectural design practice is time-consuming and costly because of the need to create a luminance map for each time step throughout the entire year [21]. Daylighting design by integrating the principles of optimization and energy efficiency. This new design philosophy uses the data-driven capabilities of machine learning to create efficient light-shelf designs that meet the needs of the building environment. The results are shown in Figure 2 [Weather File - Program Simulation - Input Parameters - Machine Learning Algorithms on Daylighting Prediction: Output Parameters].

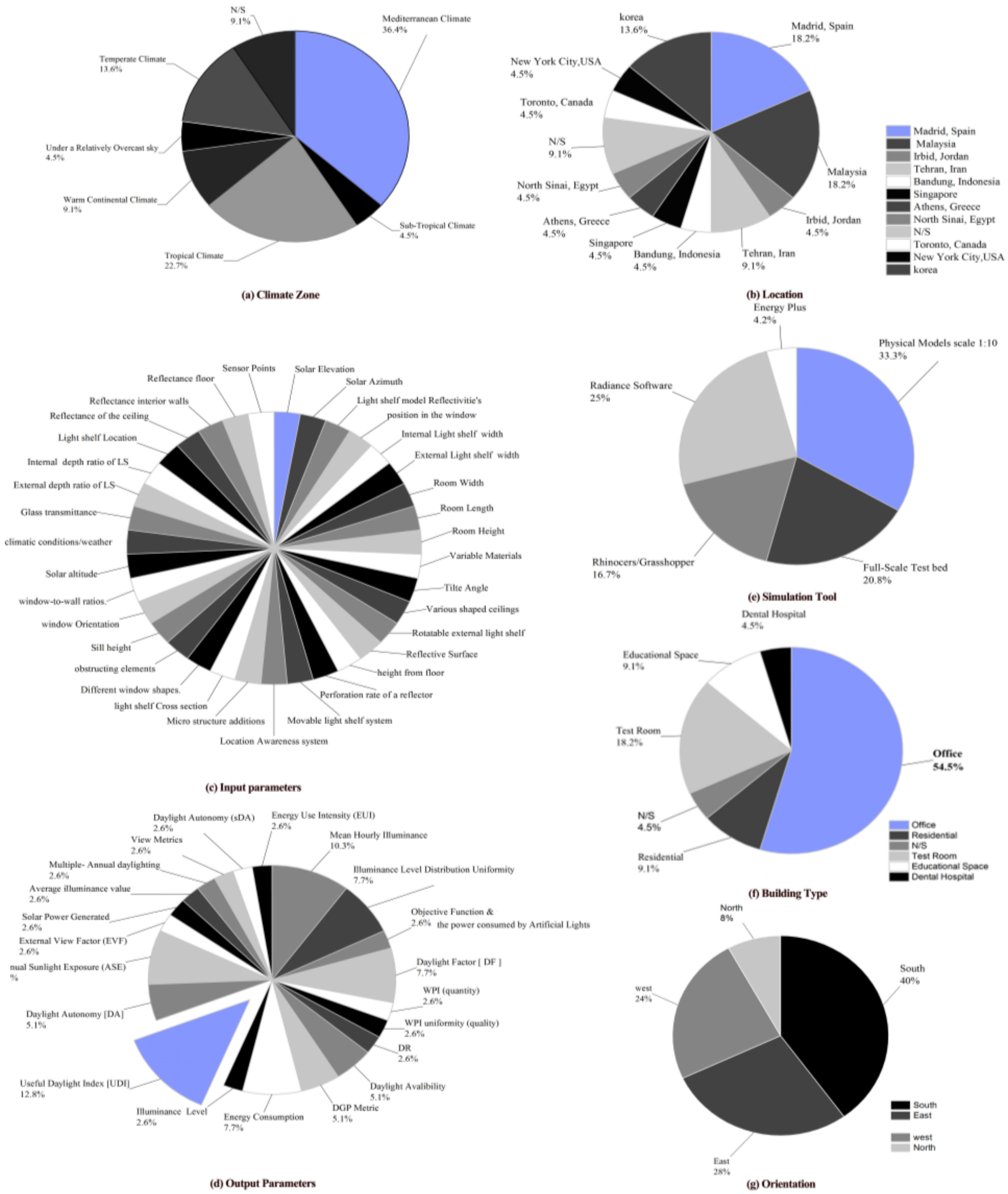


Fig. 2. Summary of review findings and frequency percentage distributions: (a) Climate zone, (b) Location, (c) input parameters, (d) output parameters, (e) Simulation tools, (f) Building Type, (g) Orientation (analyzed by the authors in table 2 is provided Appendix A)

Unchecked efforts to let as much natural light into a building as possible might result in overly bright interiors that hinder visibility or cause eye strain. Physical models, photos, measurements taken on-site, rules of thumb, legislation, and computational simulations are just a few of the modeling techniques developed to assess the amount of daylight in buildings [42]. Due to mistakes made during the whole building life cycle, there is usually a significant disparity between the desired (design phase) and actual (operation phase) performance levels [43].

5.2. Machine Learning And Applications In Light Shelf Design

For daylight performance prediction, simulations were computationally expensive, which could be impractical in an iterative design process. To obtain more accurate results for daylight metrics and to compare the virtual and actual data, it might take more time to experiment with various lighting simulation programs for indoor environments [44]. The method uses machine learning [41] and artificial neural networks (ANN), both of which have been shown to work well for solving complex non-linear problems [7]. The concept of machine learning has been used to approach

Machine learning algorithms can be used to optimize light shelf design, allowing designers to create increasingly efficient designs with greater accuracy. The algorithm can be adjusted to achieve various outcomes and can be used to create a more responsive and adaptive design that meets the needs of the occupants.

Office buildings can benefit from more daylight and better lighting with the use of integrated control lighting systems and daylight strategies (such as light shelves and slanted ceilings). Data optimization for the building's early operation stage is still lacking, which has an effect on the economic side [45]. The possibility of developing a more efficient algorithm for the daylighting concept of light shelf design by leveraging the power of machine learning to create a more responsive and adaptable design. To decrease energy usage and make use of renewable energy, the design proposes integrating solar panels with a shelf to support electricity and LED lights [46]. The essential idea behind machine learning is to construct algorithms that can take in data as input and, using statistical analysis, provide predictions about the output. Because of its significant influence on decision-making, ML is becoming more popular and significant [47]. The algorithm is based on the parameters of the inputs on the light shelf and can be adjusted to create different results based on the desired output metrics.

Neural networks can accurately model the relationship between light and the environment, allowing designers to create light shelves that maximize daylighting while minimizing energy costs. Neural networks are not limited to light shelf design but can be used to optimize any type of daylighting system, including skylights, windows, and exterior facades. Using artificial neural networks to analyze and optimize the performance of the light shelf, these benefits can be further enhanced. The durability of neural network models is in doubt because they are still "black box" the sensitivity of the prediction outcomes dependent on the chosen neural network design and the randomly chosen initial weight values [48]. There has been an uptick in the use of building automation systems, especially daylight connected control systems [9]. They reasoned that building automation systems may be optimized in many ways; thus, they presented a methodology to assess their potential [43]. The future light shelf-designed system should work with the sensors found on smartphones and include plans for applications that can be used in practical architectural settings [49].

6. Conclusion

In this study, we attempted to determine how to combine simple feedback loops with light shelf designs that have multiple parameters and the concept of machine learning. It has been shown that practitioners have no interest in designing a light shelf based on natural light parameters as a predictive model for the efficiency of indoor space lighting and automating it based on a dataset for building performance and space occupants. Machine-learning generation of quick models using learning patterns in numerical datasets acquired from actual measurements or simulations is a current trend in architecture disciplines. The machine learning algorithms may not only reduce the design and testing times but also provide sensibility by analyzing the trends of different daylighting design techniques.

The review work of this study emphasizes a different method for creating predictive light shelf models based on MLAs. Early design stage integration of machine learning for architectural daylighting performance. This study focuses on defining the parameters for parametrically comparing the light shelf design with other design options and predicting the control points for the design’s relationship to daylight availability metrics.

The analysis, employing machine learning techniques, revealed the following insights regarding the examination of light shelf properties: Spain and Malaysia were the primary focus, collectively accounting for 18.2% of the research, followed by Korea at 13.6%, Iran at 9.1%, and Indonesia, Greece, and Singapore each at 4.5%.

Regarding the investigated climatic conditions, the Mediterranean climate was prominently featured at 36.4%, followed by tropical climates at 22.7%, temperate climates at 13.6%, and continental warm climates at 9.1%.

Regarding the assessment of simulation tools, the findings indicate the following distribution: a physical model scaled at 1:10 accounted for 33.3% of the studies, radiance software simulation was employed in 25% of the cases, full-scale test beds were used in 20.8%, and parametric software such as Rhino was used in 16.7% of the analyses. In terms of the examined building types, the distribution was as follows: office buildings constituted the majority at 54.5 % followed by test rooms at 18.2%, with educational and residential buildings each accounting for 9.1%, and dental clinics and hospitals at 4.5%.

All critical design inputs for the light shelf were collated as input parameters, as shown in Table 2. Similarly, all significant daylighting metrics were compiled as output parameters in Table 2. Among these metrics, the most notable were the Useful Daylight Index (UDI) at 12.8% and the mean hourly illuminance at 10.3%.

A set of techniques known as a machine learning algorithm is used to forecast future data or make decisions during the design process. The advantages of daylighting are highly dependent on daylight availability, which varies widely depending on latitude, sun path, sky conditions, and weather conditions. Thus, by combining artificial intelligence techniques with evolutionary algorithms that can improve the design of light shelf parameters to meet daylighting requirements results in energy saving. The Useful Daylight Index (UDI) stands out as the most notable index to have a significant influence on shaping future light shelf designs using machine learning concepts.

Daylight simulation integrates machine learning algorithms at an early stage, thereby reducing time-consuming assessments and building performance cost. Some researchers who are accustomed to machine learning techniques may not know how to handle these challenges. Data-driven approaches are divided into two categories: artificial intelligence approaches, which include artificial neural networks and fuzzy logic, and statistical approaches include regression-based models such as Gaussian process (GP) regression and a probabilistic Bayesian learning framework.

Finally, knowledge gaps are also covered, suggesting potential uses of these strategies in future architectural practice. Further study into the associated architectural applications is strongly advised because this research field is not yet sufficiently developed.

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Author Contributions

O. S. Zekry was responsible for the conceptualization, validation, resources, data curation, software development, and project administration. A. A. Fekry and R. D. Hamed jointly contributed to the methodology, formal analysis, investigation, original draft preparation, review and editing, visualization, supervision. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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Appendix A

Table 2. A synopsis of how various parameters of light shelves impact in daylighting and machine learning concepts (Drawn by the authors)

Authors	Year	Country	Climate Zone	Latitude	Building Type	Daylighting Strategies	Orientation	Light shelf Shape /Cross Section	Light shelf Concept / Variables to Improve Its Performance	Input parameters	Simulation Program	Output Parameters	ML Concept
Soler and Oteiza	1996	Madrid, Spain	Mediterranean Climate	40.4 ° N, 4.4 ° W	Office	Light Shelf	South	Internal & External/ Rectangular	Fixed light shelf variables	Solar Elevation Aluminium painted with three Layers of white matt paint. Internal & External parts	Scale Models I:10	Mean Hourly Illuminance	Not Available
Soler and Oteiza	1997	Madrid, Spain	Mediterranean Climate	40.4"N, 4.4"w	Office	Light Shelf	South	Internal & External/ Rectangular Aluminium	Fixed light shelf variables	solar Elevation Solar Azimuth Light shelf model Reflectivitie's position in the window Internal width External width Room Width Room Length Room Height	Scale Models I:10	Mean Hourly Illuminance	Not Available
Claros and Soler	2001	Madrid, Spain	Mediterranean Climate	40.4"N, 4.4"w	N/S	Light shelves & Overhang	South	Methacrylate & Mirror	Fixed light shelf variables	variable materiand externalal / reflectance	Scale Model 1:10	**Mean Hourly Illuminance**	Not Available
Claros and Soler	2002	Madrid, Spain	Mediterranean Climate	40.4"N, 4.4"w	Test Room	Light Shelf	South	Row Aluminium painted with three layers of : White matte White opaque Methacrylate Mirror Row Aluminium	Width Angle Height Reflectivity	Width Angle Height Reflectivity	Scale Model 1:10 Adeline	Mean Hourly Illuminance	Not Available
Freewan et al.	2008	Irbid, Jordan	Sub-Tropical Climate	31.963158	Test Room	Light Shelf & ceiling geometry	South	Rectangular	Fixed light shelf variables	Angle Various shaped ceilings [curved, chamfered, sloped upward from the window]	Radiance simulations	Illuminance Level Distribution Uniformity	Not Available
Raphael	2011	Singapore	Tropical Climate	1.4◦	Office	Active Control of Light Shelves	East West	Internal + External Rectangular	Rotate external Angle width internal part	Height Rotatable external light shelf Adapting the angle of High reflectance ceiling Internal light shelf W is varied by moving A using a motor. Variation in width by adding more moveable parts like using a motor. varied by moving the top part A. The bottom part B is fixed	Radiance PGSL	Objective Function the sum of the penalty and the power consumed by Artificial Lights	Not Available
Lim and Ahmad	2015	Malaysia	Tropical Climate	latitude 1 °330 N longitude 103°370 E	Office	Internal Light Shelf	East	Rectangular	Height Shape	Reflectivity Room Width Room Length Room Height	Scale Model 1:20	DF WPI (quantity) WPI uniformity (quality)	Not Available
Lim and Heng	2016	Malaysia	Tropical Climate	1° N to 6° 45'N	Office	Dynamic Internal Shelf	North East West South	Rectangular	Shape Height Width	Hight from lintel width Shape Room Width Room Length Room Height	Radiance Virtual Environment (IES-VE) Scale Model 1:20	DR DF	Not Available
Meresi	2016	Athens, Greece	Mediterranean Climate [IWEC]	37.98381	Educational Space	Light Shelf & Blinds	South	Rectangular	Width Angle Reflectivity	width Angle Height Reflectivity internal +external External blinds Obstacles	Radiance Software Ecotect®	DF	Not Available

Authors	Year	Country	Climate Zone	Latitude	Building Type	Daylighting Strategies	Orientation	Light shelf Shape /Cross Section	Light shelf Concept / Variables to Improve Its Performance	Input parameters	Simulation Program	Output Parameters	ML Concept
Moazzeni et al.	2016	Tehran, Iran	Mediterranean, Hot Summer	(35″411N, 51″251E)	Educational Space	Light Shelf [External + Internal]	Southern Orientation Eastern Western Orientations Ex[Five Angles Of 0-5-10-20-30 Degrees]	Rectangular External [0.3-0.6-0.9 -1.2 m] Internal [0-0.3-0.60.8 - 1 m]	Width Angle	Light shelf width Lightshelf Rotation Angle Reflective Surface	Radiance, which uses a ray-tracing method for Simulation	Daylight Avalibility [Partial Daylit Overlit] DGP Metric	Not Available
Lee et al.	2017	N/S	N/S	N/S	Test Room	Perforated Light Shelf [External]	South	Rectangular	Perforation rate of a reflector Angle Width	Perforation rate of a reflector Angle Width height from floor Angle range Room Width Room Length Room Height	Real Scale	Energy Consumption	Not Available
Lee, Kim, et al.	2017	N/S	N/S	N/S	Residential	Light Shelf & Location Awareness Technology [External]	South	Rectangular	Divide 4 Rotated parts	Fixed light-shelf system without location awareness Movable light-shelf system without location awareness Movable light-shelf system with location awareness Angle	Full-Scale testbed	Consumption of Electric Power	Not Available
Youssef et al.	2017	North Sinai, Egypt	Mediterranean Climate	30.282365	Residential	Light Shelf	South	Concave Rectangular Convex	Concave Rectangular Convex	Variable Width Depth Height Materials Cross section Microstructure additions	Rhino Grasshopper	illuminance level Daylight Glare Probability	Not Available
Berardi and Anarak	2018	Toronto, Canada	Continental Climate (716240_CWEC weather)	43° 40 N	Office	Light Shelf	East West	Rectangular **W1** [left external width] **w2** [right external width] W middle width D external depth d' internal depth W1' internal width W2' internal width W' internal width	Fixed light shelf variables	different window-to-wall ratios. different window shapes. façade orientation. external obstructing elements. Widow width Head Height Sill height Solar azimuth Solar altitude Top of light shelf Bottom of light shelf Wall thickness	AGi32 based Energy Plus	UDI DA ASE	Not Available
Mangkuto et al.	2018	Bandung, Indonesia	Under a Relatively Overcast sky	6.93°S, 107.61°E	Dental Hospital	Light Shelf	East Façades West Façades	Rectangular	Width Angle Reflectivity	External widths Internal widths External tilt angles Secularity of the light shelf's East façade west façade materials variables: inserting the red, green, blue (RGB) Reflectance's Secularity Roughness Room Width Room Length Room Height	DIVA-for-Rhino Octopus plug in	Spatial Daylight Autonomy (sDA) Annual Sunlight Exposure (ASE) External View Factor (EVF)	Not Available

Authors	Year	Country	Climate Zone	Latitude	Building Type	Daylighting Strategies	Orientation	Light shelf Shape /Cross Section	Light shelf Concept / Variables to Improve Its Performance	Input parameters	Simulation Program	Output Parameters	ML Concept
Lee et al.	2018	korea	Temperate 57.3600" Climate 127° 1'	37° 31' N and 28.6032" E.	Test Room	External Light Shelf with a Width-Adjustable Reflector in six stages at 0.1m intervals (from 0.1m to 0.6 m)	South	Rectangular/small Flat parts (width variables)	Light shelf with a width adjustable reflector	Angle Control [-0,0,10,20,30] Width [.10,.20,.30,.40,.50,.60] fixed Height fixed Reflectivity one hour calculated for [summer, middle season, and winter] Room Width Room Length Room Height	Test bed + Artificial chamber with physical tools	Lighting Energy Consumption Uniformity ratio of illumination	Not Available
Lee	2019	Seoul, South Korea	Temperate 57.3600" Climate 127° 1'	37° 31' N and 28.6032" E.	Office	Light shelf + Solar Module	South	Rectangular	Angle	Angle Width Height Reflectivity	Full-Scale /Test Bed	Energy Consumption of lighting Solar Power Generated	Not Available
Lee et al.	2019	Seoul, South Korea	Temperate Climate 37	° 31' 57.3600" N and 127° 1' 28.6032" E.	Office	External curvature light shelf	N/S	Curvature	Curvature Angle	Height External Reflectance Width Angle Curvature (arc angle) Range 3 seasons [summer-mid season- winter]	Real Scale	Uniformity Ratio Uniformity Indoor Illuminance	Not Available
Ahmed et al.	2020	Malaysia	Tropical Climate (EPW)	5.4141° N, 100.3288° E	Office	Light Shelf (L-Ss) [External + Internal]	South	Rectangular	Position height of LS [**PH]** External depth ratio of LS **[EDR]** Internal depth ratio of LS **[IDR]** External part angle of LS **[EPA]** Internal part angle of LS **[IPA]**	climatic conditions/weather data Base Case (BC) model (BC) improved model Light shelf Geometry Light shelf Reflectance Light shelf dimensions the inclination angle of the external portion Daylight Sensors Window-Wall-Ratio was 40% Floor Reflectance Ceiling Reflectance Walls Reflectance Glass transmittance Orientation False ceiling **Light-shelf design parameters** Position height of LS **[PH]** External depth ratio of LS **[EDR]** Internal depth ratio of LS **[IDR]** External part angle of LS**[EPA]** Internal part angle of LS**[IPA]**	physical scaled model (lux meter instrument) Radiance simulation engine Grasshopper parametric software Honeybee plugin Ladybug plugin Galapagos plugin	UDI	**Linear Regression Analysis (R2)**
Rania Labib	2021	New York City, USA	Humid Continental Climate	40.730610	Office	Light Shelf	North South East	Rectangular	Input parameters	Room Hight Glazing Ratio Light shelf Depth Light shelf Location Walls Reflectance Light shelf reflectance Ceiling Reflectance Floor reflectance Glazing transmittance Window orientation	Radiance Daysim	Single- point-in-time simulations Multiple-annual daylighting Average illuminance value inside	**Artificial Neural Network**

Authers	Year	Country	Climate Zone	Latitude	Building Type	Daylighting Strategies	Orientation	Light shelf Shape /Cross Section	Light shelf Concept / Variables to Improve Its Performance	Input parameters	Simulation Program	Output Parameters	ML Concept
Nourkojouri et al.	2021	Tehran, Iran	Mediterranean, Hot Summer	(35˝411N, 51˝251E)	Office	**Window's Specification** [Height -width- orientation] **Shading Slats** [louvers]	North South East West	N/S	Input parameters	Room Width Room Length window Height (W.H) window Sill Height (S.H) Window Glass Type Window orientation Interior surfaces reflectance factor **Shading state** [No shading – 15cm horizontal louvre] **Variables** window divisions Window height (m) Window Sill Height (m)	**Grasshopper** **Colibri plugin** **Honeybee plugin** **python code**	Daylight Metrics UDI mDA sDA **Glare Metrics** sVD ASE **View Metrics** View Range View Depth View Factor	**Artificial Neural Network Architecture Training data= 2300 Testing=580**
Bahdad et al.	2022	Malaysia	Tropical Climate	5.4141° N, 100.3288° E	Office	Light Shelf (L-Ss) [External + Internal]	South	Rectangular	Position height **(Pos. H)** Exterior portion angle **(Ext. A)** Interior portion angle **(Int. A)** Exterior portion depth ratio **(Ext.DR)** Interior portion depth ratio **(Int. DR)**	Position height (Pos. H) Exterior portion angle (Ext. A) Interior portion angle (Int. A) Exterior portion depth ratio (Ext.) Interior portion depth ratio (Int. DR) window-to-wall(WWR 90%) Reflectance of the ceiling Reflectance interior walls Reflectance exterior walls Reflectance floor Reflectance L-Ss Sensor Points	**Grasshopper parametric software** Honeybee plugin Ladybug plugin octopus plugin **Optimization Technique** NSGA-II	Daylight Availability Daylight Autonomy (sDA) Useful Daylight Illuminance (UDI) Energy Efficiency Energy Use Intensity (EUI)	**Not Available Test data = 6124**

N/A not available; N/S not specific