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Optimizing Natural Lighting to Reduce Discomfort and Mobility Issues in Schools for Visually Impaired Children, Bangladesh

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Abstract

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Proper natural lighting is essential for developing comfortable learning environments, especially for visually impaired children. It develops general comfort and spatial awareness and lowers visual strain. However, typical schools in Bangladesh frequently lack proper lighting solutions. While improper lighting makes the learning process difficult for normally sighted children, the impact for visually challenged students is much worse as it directly affects their mobility training. The study assesses existing lighting conditions in a typical classroom of the existing modular school building and offers practical design interventions like strategic window placement or shading screens. Problems are identified by simulating the lighting condition through high-fidelity software, and practical modifications are suggested based on simulating each design intervention. The findings will guide architects, educators, and policymakers in developing inclusive learning settings. This study emphasizes the importance of well-designed natural lighting in improving educational outcomes for visually impaired children in Bangladesh.

Keywords: visual impairment, blind, inclusive design, classroom, corridor, lighting, elevation.

1. Introduction

Lighting for children with visual impairments is a crucial aspect of specialized schools, but that is usually overlooked. It is essential to recognize that children with visual impairments often have problems with light sensitivity, glare, and contrast sensitivity (Gould & Herman Gould, 2003). Their difficulties are compounded by poorly designed learning environments in classrooms and other impassable learning or recreational spaces in school. These challenges in their surroundings can cause eye strain and headaches and make it hard to do the basics like read, write, and get around the school. (Ghasemi Fard et al, 2023). These issues cause an unfriendly school atmosphere and result in a high dropout rate among visually impaired students (Shamima Nasrain, 2017). Ideal lighting for normally sighted people varies between 300 and 500 lux since these are friendly to the eyes and can help improve vision. Developing appropriate lighting standards for visually impaired individuals has been challenging since different light levels affect people in diverse ways (Lehon, 1980). Glaucoma, Macular degeneration, and aniridia need contrast to detect things as they lose peripheral vision. Retinitis Pigmentosa, Diabetic Retinopathy, and Ocular Albinism need the least contrast and minimum glare. Due to different low vision disabilities, a wide spectrum of lighting options may be required to meet their usage requirements. Using different lighting fixtures to solve this issue is very costly, and thus, in developing countries, visually impaired students are bound to attend school in this unfriendly atmosphere and gain very less from school. Mobility training is often neglected as moving around causes eye strain and headaches. Often, the only thing they learn is reading braille. The basic learnings like mobility or doing daily chores independently remain unlearned. A study reveals that the optimal arrangement of the lighting in the classroom can considerably enhance the educational climate for such students and consequently enhance students' orientation and interaction with environments (Gellhaus & Olson, 1993). This can only be solved through architectural modifications to accommodate natural lighting conditions free from glare and environments that suit their needs without entirely depending on costly lighting fixtures. A study shows that daylight has positive impacts on the students' learning environment and performance. (Altomonte, 2009; Kim et al., 2014). In this study, the architectural façade and opening design of corridors of the existing modular

classrooms of Bangladesh are considered, and appropriate luminance levels are examined to accommodate different types of visual impairments. This includes changing window size and window levels, setting up adequate lighting controls, minimizing glare, and utilizing natural light to support the students’ learning (Lehon, 1980). The research presents comprehensive global design guidelines for creating inclusive, multisensory learning environments that serve visually impaired students to address these challenges. The research employs Bangladesh as a case study, aligning global benchmarks with local challenges and advocating for high-quality educational facilities that ensure accessibility for children worldwide. This document is organized into five parts. The first chapter reviews the necessity of proper lighting. The second presents the analysis of light requirement for each user group. The third chapter analyses the existing daylight condition, and the fourth and fifth chapters give design guidelines comparing different elevation treatments and discuss the main contributions of this paper.

3. Material and Methods

The methodology for this study adopts a modular approach to designing optimal lighting conditions specifically tailored for individuals with visual impairments. Instead of relying on standard archetypal spaces, which may not adequately meet the diverse lighting needs of this population, we explore adaptive lighting strategies that respond dynamically to varying conditions. First, we classified various types of visual impairments (VI) and specified the specific lighting requirements for each type based on a thorough literature review. The understanding underlying this was used to revise lighting standards, pointing out that traditional lighting does not meet the comfort of visual perception for individuals with visual impairments. Building on this foundational analysis, we focused on creating modular solutions that can be adjusted to optimize illumination levels across different learning environments. These solutions include adaptable luminous environments that can be altered according to the users’ requirements, spatial conditions, and functional purposes. To support these modular changes, further high-fidelity simulations were done with the help of “Grasshopper”, a visual programming language and environment that runs within Rhinoceros 3D. The simulations allowed for comparing specific configurations and their influence regarding visual navigation, lighting, and comfort. The last process of the study concerned the combination of these optimized lighting configurations with modular facade layouts. We assessed various facade strategies to ensure that the proposed modular units support natural lighting, minimize glare, and maintain optimal luminance levels for a range of visual impairments. By evaluating different ratios of openings and shading devices, we created adaptable facade designs that can be implemented in diverse educational settings.

2. Lighting Level Requirements for Different Spaces

According to WHO, visual impairment is recognized as a loss of visual acuity or visual field that, despite adequate refractive correction, impairs the performance of visual activities in daily functioning (Tapu et al., 2020). This impairment is classified into blindness and low vision (AlSoufi, 2014). Some of the main causes of low vision are cataracts, retinopathy associated with diabetes, glaucoma, and macular degeneration (Bourne et al., 2021). Glaucoma is usually characterized by progressive peripheral field loss, which becomes worse in poor lighting. A cataract is a cloudy area in the lens of the eye that decreases vision. Retinitis pigmentosa causes cells in the retina to break down slowly over time, causing vision loss. (*Retinitis Pigmentosa* | *National Eye Institute*, n.d.) Due to macular degeneration, a major part of the central vision can be lost. Ocular albinism is associated with nystagmus and reduced visual acuity. Aniridia is a condition characterized by iris hyperplasia and is often associated with reduced visual acuity and light sensitivity. Due to different low vision disabilities, a wide spectrum of lighting options may be required to meet their usage requirements. Normal lighting varies between 300-500 lux since these are friendly to the eyes and can help improve vision. Developing appropriate lighting standards for visually impaired individuals has been challenging since different light levels affect people in diverse ways (Lehon, 1980). But study reveals that the optimal arrangement of the lighting in classroom can considerably enhance the educational climate for such students and consequently enhance students’ orientation and interaction with environments (Gellhaus & Olson, 1993)

Table 1. Ideal lighting level per visual impairment

Condition	Ideal Lighting (lux)	Recommendations
Glaucoma	500-1000(Bowers et al., 2001)	Diffused lighting to reduce glare; enhance contrast for peripheral vision.
Cataract	1100-2000(Yong et al., 2024)	Ensure even lighting distribution.
Retinitis Pigmentosa	350-800(Matusiak& Fosse, 2009)	Brighter lighting to enhance remaining visual field; avoid direct light to prevent glare.
Diabetic Retinopathy	300-600(Yong et al., 2024)	Reduce glare and improve contrast sensitivity; ensure even lighting distribution.
Macular Degeneration	500-600(Bowers et al., 2001)	Focused task lighting for central vision; adjustable lighting to suit needs.
Ocular albinism	424-1190 According photosensitivity level (Matusiak & Fosse, 2009)	Reduce glare and improve contrast sensitivity;
Aniridia	194-813 (Matusiak & Fosse, 2009)	enhance contrast for peripheral vision

With lighting level, the next most important part is designing lighting distribution. As almost all the groups of visually impaired children have photosensitivity and sudden changes in lighting level make them very uncomfortable.

The ideal lighting level is for task performing, i.e., for classrooms. Classrooms can be designed for 3 different groups, Group 1- for sighted children, Retinitis Pigmentosa, Diabetic Retinopathy (Lower luminance level)
 Group 2- for Glaucoma, Macular Degeneration, and Aniridia (mid-luminance level, Aniridia has high photosensitivity)
 Group 3- for cataracts and ocular albinism with the highest luminance level.

However, to design proper lighting for visually impaired students, we must also consider the ideal minimal lighting level for normally sighted people in different areas of the school. This is for the teachers and caregivers who must perform their tasks without obstacles.

Table 2. Ideal illuminance levels for school (Loe et al., 1999).

Space Type	Standard Illuminance (lux)
1. General Teaching Spaces	300 *
2. Teaching Spaces with close and detailed work (e.g., art and craft rooms)	500 *
3. Circulation Spaces: Corridors	80
Stairs	120
Entrance halls	175
lobbies & waiting areas	250
Reception areas	350
4. Atria	400 *

4. Results

The Classroom

We have tested 6 different elevation treatments on the modular classroom layout (Fig1) in GOVT. School in Bangladesh. All Openings Have Single Pane Clear Glass with 0.71 Transmittance.

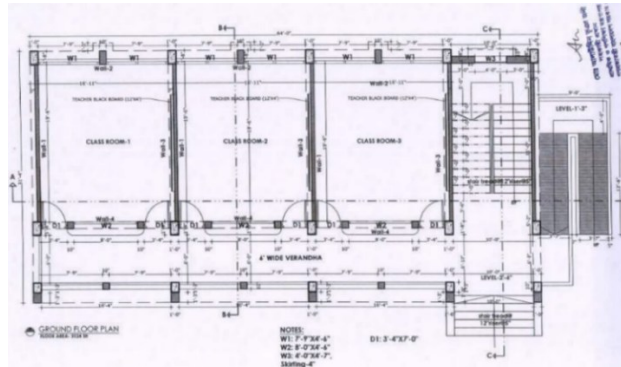


Figure 1. Existing Govt. Modular Primary school building plan

Source: Fourth Primary Education Development Program (PEDP4) (October 2018).

Classroom Façade 1- Existing Condition

The existing classroom has a Sill height of 36” and a window height of 60” (Fig. 2). The north facade has 52% opening, the South facade has 20% opening as a window and 5% opening as 2 doors, opening into the corridor. The maximum luminance is 980.36 lux near the south windows, and the minimum is 113 lux near the north façade (Fig2).

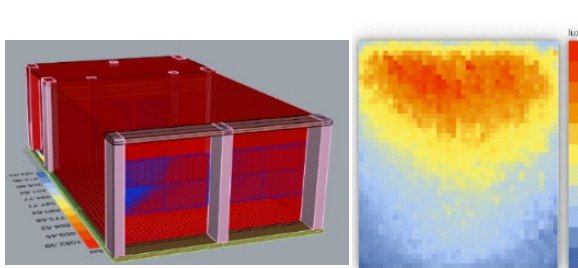


Figure 3. Façade 1; Existing Sill height 36”, window height 60”.

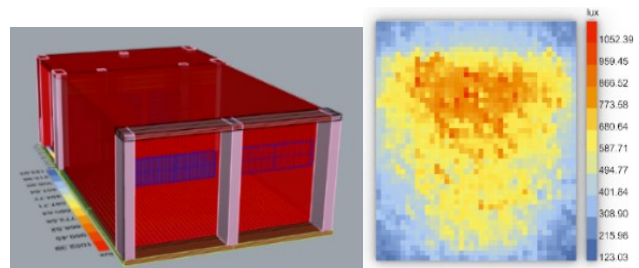


Figure 2. Façade 2; Sill height 60”, window height 30”
 Source: Author’s Simulation.

Classroom Façade 2

The sill height was changed to 60”, and the window height was changed to 30”.(Fig. 3) The North facade has an 18% opening, and the South facade has 20% opening as a window and a 5% opening as 2 doors, opening into the corridor. Maximum luminance is 1052.39 lux in the middle of the room, and minimum 123 lux near walls and corners (Fig. 3).

Classroom Façade 3

Sill height 82”, window height 27.24”. The north facade has 18% opening, and the South facade has 20% opening as window and 5% opening as 2 doors, opening into the corridor. Maximum luminance is 647.67 lux in the middle of the room and minimum 115.16 lux near walls and corners (Fig4).

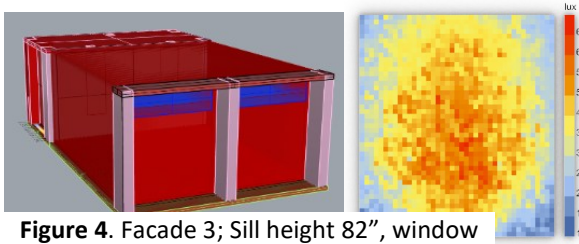


Figure 4. Façade 3; Sill height 82”, window height 27.24”

Source: Author’s Simulation.

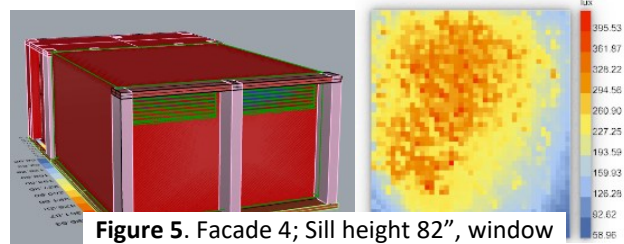


Figure 5. Façade 4; Sill height 82”, window height 27.24”

Source: Author’s Simulation.

Classroom Façade 4

Sill height 82”, window height 27.24” with horizontal louvers at a 30-degree angle. The north facade has 18% opening, the South facade has 20% opening as a window, and 5% opening as 2 doors, opening into the corridor. Maximum luminance is 395.5 lux on the left side and in the middle of the room, and minimum 60-100 lux near walls and (Fig5).

Classroom Façade 5

Sill height 3”, window height 90” with louvre. The north facade has 60% opening, the South facade has 20% opening as a window and 5% opening as 2 doors, opening into the corridor. The maximum luminance is 1924.8 lux in middle of the room, and minimum 60 lux near walls and corners and north facade. Louvres depth 5”, shade count 47 with distance 3” from one another, angle 30 degree (fig6).

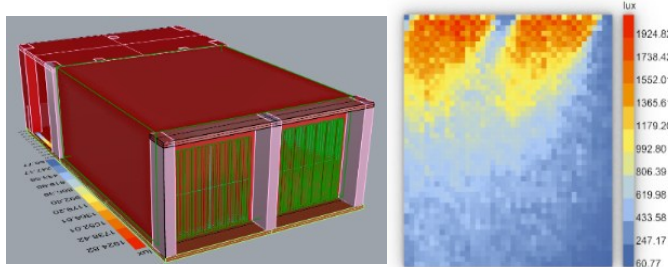


Figure 6. Façade 5; Sill height 3in, window height 90in

Source: Author’s Simulation.

Classroom Façade 6

Jali Pattern-1: Pattern 2.5”x7.5” perforation after solid wall of 1’-2”. Maximum light: 2739 lux. 400-800 LUX on maximum surface area. Minimum light 27-50 lux near the columns. (fig7).

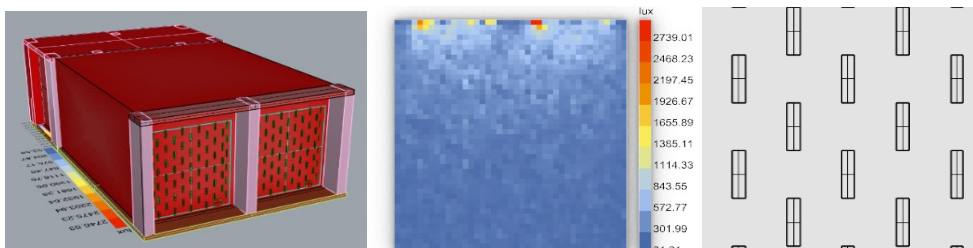


Figure 7. Façade 9; jali pattern 1

Source: Author’s Simulation.

Classroom Façade 7

Jali Pattern-2: Pattern of 3.5”. Maximum light 3301 lux. 450-1000 LUX on maximum surface area. Minimum light 130 lux near the columns (Fig. 8).

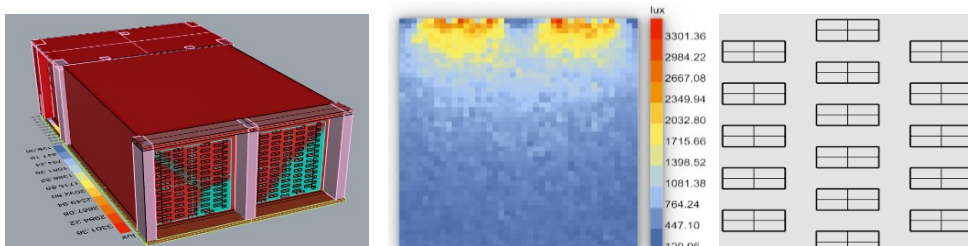


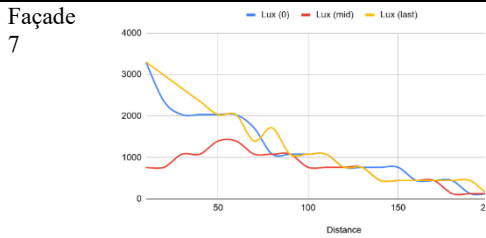
Figure 8. Façade 10; jali pattern 2

Source: Author’s Simulation.

Simulation graphs showing change of luminance level at 3 lines, at left side (blue line), middle (red line), and right side (yellow line) of the room. (lines taken at right angle from window position). From the graphs, we can understand the light distribution quality and amount of glare caused by each façade.

Table 3. Graph Comparison Source: Author’s Calculation.

Façade	Graph	Description
Façade 1		The peak point can be seen close to the window. Most sudden changes are seen in the middle line. The highest level in the beginning indicates the effect of glare, and the decreasing graph shows very poor light distribution.
Façade 2		The peak point can be seen in the middle of the room; changes in lighting level are not that sudden, which means moderate glare. An almost gradual change shows moderate light distribution.
Façade 3		The peak point can be seen in the lower middle part of the room; some sudden changes are seen in this line too. Light change is gradual, and no sudden change shows good light distribution and very little glare.
Façade 4		The peak point can be seen in the upper middle. the change in luminance here seems gradual till the midpoint, then the change becomes very insignificant, side (ending) has gradual change. Light distribution is poor in part of the room.
Façade 5		The peak point can be seen at the nearest point of the window, near the south façade. The luminance near the south façade is very high, then decreases till the end line. Light distribution is poor and will cause too much glare.
Façade 6		The peak point can be seen at the nearest point of the window, near the south façade. Glare is low near windows and almost zero in the rest of the room.



A peak point is seen close to the window. Though light distribution seems good in the maximum area of the room, near the windows, the light will cause too much glare.

CORRIDOR

Corridor Façade 1 -Existing Condition

North facade has 20% opening, South facade has 65% opening. Opening into corridor. Railing height is 36”, opening height 6’. Maximum luminance is 5465 lux across railing, and minimum 1757 lux near north facade.

Corridor Façade 2

With full height opening and outdoor louvres, 5” depth and 0-degree angle, maximum luminance 949 lux beside railing (on both side of the middle column), Minimum luminance 7.18 lux which is too low.

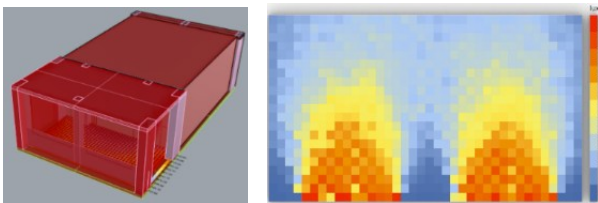


Figure 10. Corridor facade 1; existing condition
Source: Author’s Simulation.

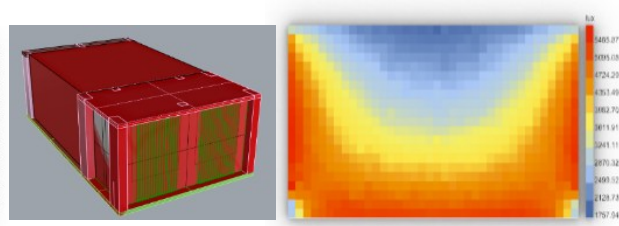


Figure 9. Corridor facade 2; with outdoor louvres
Source: Author’s Simulation.

Corridor Façade 3

Pattern 5.5” x1’-6” perforation after solid wall of 1’-6.5”. Maximum light 200-305 lux, on maximum surface area. Minimum light 27-50 lux near the columns.

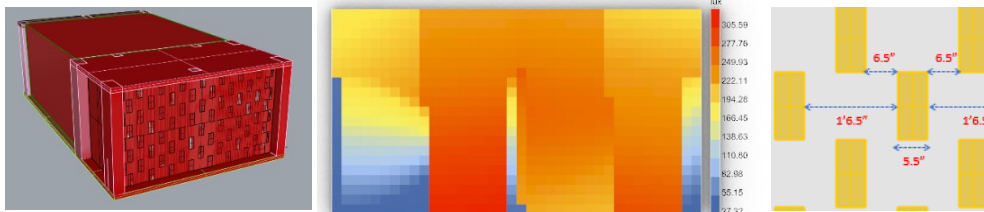


Figure 11. Corridor facade 3; Jali pattern 1.

Corridor Façade 4

Pattern 6”x1’ perforation after solid wall of 1’. Maximum light 2982 lux, near jali wall. Minimum light 762 lux near the opposite wall.

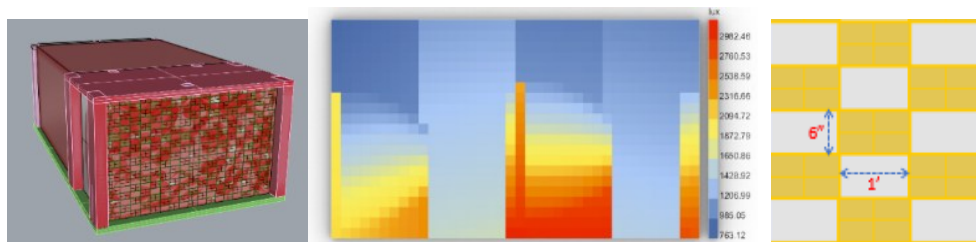


Figure 12. Corridor facade 4; Jali pattern 2.

Corridor Façade 5

8.5”x6.5” perforation after solid wall of 9.5”. Maximum light 453 lux, maximum surface area has 150-173 lux. Minimum light 63-93 lux near the columns. 300-400 lux is coming at intervals. Which is creating a better contrast.

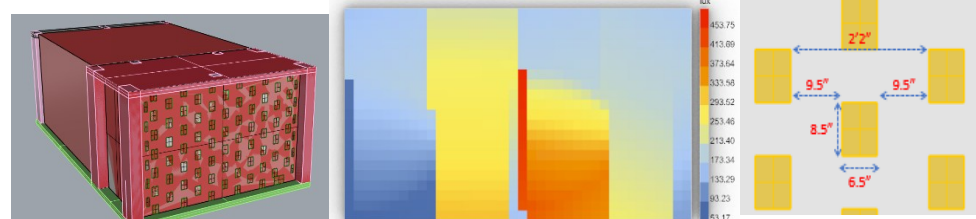


Figure 13. Corridor facade 5; Jali pattern 3.

Design Guidelines

Classrooms

The existing façade of classroom does not provide ideal lighting, and poor light distribution will cause too much glare for all groups. The simulation result shows that the higher the sill level, light distribution is better. All classrooms are considered to have a corridor on the south side and fixed openings on this side. Glaucoma, Macular degeneration, and aniridia need contrast to detect things as they lose peripheral vision. Retinitis Pigmentosa, Diabetic Retinopathy, and Ocular Albinism need the least contrast and minimum glare.

Table 4. Classroom Façade Options Comparison. *Source: Author’s Calculation.*

Façade	North Façade Opening	Max Luminance (lux)	Min Luminance (lux)	Average Luminance in maximum area (lux)	Notes
Façade 1 - Existing Condition	52%	980.36	113	700-800	Very poor light transition, not suitable for any group
Façade 2	18%	1052.39	123	550-650	Good for group 1
Façade 3	18%	674	115	350-450	Good for a combined classroom
Façade 4	18%	398.9	60-100	200-300	Low glare, low light transition, Good for photosensitive children
Façade 5	60%	1924.8	60	500-600	Moderate glare but too much bright, can work for group 3
Façade 6	2.5”x7.5” perforation	2739	27	300-400	Can work for group 3, minimum level is too low
Façade 7	6”x12” perforation	3300	129	600-700	Good for group 2

The best option for a group 1 (sighted children, Retinitis Pigmentosa, Diabetic Retinopathy) is facade 2, (Sill height 60”, window height 27.24”), as the maximum luminance is 1052 lux, maximum area of the room has 550 to 650 lux. The transition level is good, an increased sill level provides low glare. 2 is best for classrooms where practical or handicraft works are taught. Facade 4 is a good option for the group of highly photosensitive children, having the lowest glare and slowest light transition. Facade 7, jali pattern 2 is best for G, MD, and aniridia (mid-luminance level), maximum room area has illuminance from 600–700 lux. For the third group, children with cataracts will prefer façade 5, with full-height window and 30-degree louvers with reduced glare. Façade 3 shows a slower transition, and a maximum 647 lux luminance can be considered ideal for a combined classroom.

Corridor

The circulation spaces need to be designed considering all the users, children and adults (teachers and caregivers) from all groups. The minimum lighting level for circulation space is 80 lux (Loe et al., 1999). So, the corridor needs to be evenly lighted with contrast at fixed intervals with minimum glare (diffused light). The existing condition is not ideal for any group and provides very poor condition for visually impaired group.

Existing corridor façade can work in school for normally sighted children but not good for children with visual impairment. In Corridor façade 3- jali pattern 1 though light level has been acquired, this type light distribution is not good for circulation for children with peripheral vision loss. As the contrast is very low, the intervals will not be clear. Though it can be a good option for normally sighted people, not ideal for people with photosensitivity. Corridor façade 6- Jali 4 provides good contrast with diffused low-range light. In corridor façade 4- jali pattern 2, though contrast is acquired, the illuminance level is too high. So, the best elevation for corridor façade 6, with pattern 8.5”/6.5” perforation after solid wall of 9.5”, considering all groups of children.

Table 5: Corridor facade options comparison. *Source: Author’s Calculation.*

Façade	South Façade Opening ratio	Max Luminance (lux)	Min Luminance (lux)	Average Luminance in maximum area (lux)	Notes
Corridor façade 1	65%	5465	1757	400-500	High luminance transition , unsuitable for visually impaired;
Corridor façade 2	Full	949	7.18	2500-3000	Provides shading but too bright
Corridor façade 3	50.5%	305	27-50	200-250	Even light on most surfaces but low contrast, unsuitable for those with peripheral vision loss.
Corridor façade 4	24.8%	2982	762	1200-1300	High illuminance and contrast but too bright for photosensitive individuals.
Corridor façade 5	20.8%	453	63-93	250-350	Good contrast with low, diffused light, suitable for all groups;

4. Discussions

The Findings

The existing conditions in both the classroom and corridor are not suitable for the visually impaired children. The existing classroom is divided into two zones, low light and highly intense light. The transition of light is very sudden, and the distribution of light is too poor. Poor light distribution and high glare make the overall school environment unsuitable, and children find it difficult to participate in regular activities. High glare will cause eye problems in normally sighted children too, this may result in various health issues. For inclusive education, the facade design needs to be changed to facade option 3. The existing corridor can be used for normal school. Though, uncontrolled lighting makes it hard to move around with ease and hence limits movement in the corridor. In the case of visually impaired children, where walkability is very crucial for their overall growth and mobility being a must-learn skill, the existing type of corridor must not be used. For special schools, the corridor facade design can be changed to facade 5.

Implications

- Educational Impact: Better lighting conditions should be considered as one of the ways that can help the students with impaired vision since it will make the school environment better for them and lessen the dropout rate.
- Design Recommendations: Develop recommendations for the type of lighting and design of the lighting solutions for educational facilities for visually impaired people, including the principles of flexibility, control of glare, and task-oriented lighting.

Limitations

- Simulation Constraints: There are currently real-world issues, for example, dynamic daylight conditions, which might not be aptly modeled in simulation.
- Generalizability: This may call for modifications depending on the regional and architectural circumstances of each recommendation.

Future Research

- Technology Integration: Exploring advanced lighting technologies like smart lighting systems that adapt in real-time to the needs of visually impaired individuals.
- Longitudinal Studies: Conducting studies to assess the long-term impact of optimized lighting on educational outcomes and well-being.

5. Conclusions

The existing configurations of classroom and corridor lighting in the analysed school module were found to be inadequate in terms of illumination levels and uniform natural light distribution, resulting in significant visual discomfort and limited mobility for the students. In the simulations, this study showed that changes in size, location, and ratio of openings- window height changes and incorporation of louvers and jali patterns can greatly improve the daylighting conditions. In particular, the study focuses on the difficulties for visually impaired students, including those who are sensitive to light: it is necessary to minimize glare, but at the same time, the luminance should be sufficiently high for some groups. The placement of modular adjustments and shading elements proposed for the facades comes with valuable ideas for improving the learning environment for students with disabilities without relying on costly artificial lighting. Finally, the study also highlights the need for future studies into smarter forms of lighting control and potential follow-up studies to enhance these architectural approaches. Thus, following these design guidelines, educational institutions can contribute to providing comfortable visual perception and movement opportunities for students with Visual Impairments and create conditions that do not hinder the learning process and, on the contrary, will encourage independent access to learning materials for students with visual impairments.

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Conflict of Interests

The Author(s) declare(s) that there is no conflict of interest.

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