Optimization of Facade Design for Daylighting and View-to-Outside

A case study in Lecco, Lombardy, Italy

Mohamed Adel Wageh¹, Mahmoud Gadelhak²
¹politecnico di milano, polo territoriale di Lecco, Italy ²Technical University of Munich
¹mohamed.adel@mail.polimi.it ²m.gadelhak@tum.de

Minimizing the impact of shading devices on the view to the surrounding view is essential for indoor spaces that overlook exceptional scenery and views. Building facades that overlook such views require a special care not to obstruct the view to the outdoors. At the same time, poorly designed shading devices can result in high solar penetration and glare probability affecting the ability of the users to enjoy the outdoor view. In this paper, we analyze the effect of adding different shading devices and configurations to a south façade for a workshop space in Lecco, Italy. A parametric model of five types of shading devices was analyzed for the daylighting, glare and view performance. The trade-off between the objectives and the cases that achieved satisfactory performance in all three criteria were presented.

Keywords: Computational design, Daylighting, Optimization, View to outside

INTRODUCTION
This paper presents the result of an evidence base design project, for the Sustainable Building Technologies (SBT) course and studio of Architecture Design (AD), a mandatory course in architecture and building engineering master degree in Politecnico di Milano, Lecco campus. The multi-disciplinary design project aims to understand the integration between architecture, energy efficiency and construction technology, to apply innovative construction technologies and critic it per architecture design requirements.

The project’s goal was to design a multi-functional building located in La Piccola area, in the historical industrial area of Lecco city, in Lombardy, north of Italy. The building’s site is in front of the new campus of Politecnico di Milano. Site reconfiguration and the absence of residential complexes left the site with an unobstructed panoramic view of the surrounding mountains. The proposed design consists of three floors plus a ground floor with various functions related to the Politecnico di Milano, such as: sports center, library, study areas for students, auditorium, food court connected to the Lecco Market, and space for workshops with 150 m² area. The workshop space covers most of the fourth floor. In order to provide a 360° panoramic view of the surrounding mountains, the fourth floor has floor-to-ceiling
windows in all four orientations. This left the space, however, vulnerable to direct sun penetration. (see Figures 1 and 2)

Figure 2
Panoramic view from the project site. Image (A), toward the south direction. (B, C) toward south west and east

Therefore, the biggest challenge facing the proposed project was to keep the view from inside to outside with minimum obstruction in all the directions while providing sufficient daylighting and minimal glare. The studied floor had a rectangular shape with the long sides having a North-South axis with a tilted angle of 10°, and the short sides facing East and East. While the North, façades don’t receive high sun exposure for most of the day, the South façade is subject to high exposure for most of the day, throughout the year. East and West facades had a small impact on the daylighting performance of the space due to their relatively small area and being separated than the working space by the staircase and elevators cores. The four façades, especially the south, overlooks the best landscapes of Lecco since it looks directly on historical Lecco’s mountains, Resegone, San Martino, Monte Moregallo, Grigna Settentrionale e Meridionale and Monte Barro. Hence, the importance of creating a 360° panoramic view while providing enough daylight for the workshop space. (see Figure 3)

The city of Lecco has a humid subtropical climate, with hot and humid summer and cold winter. The highest sun altitude in winter is of 20.8°, while in summer 67.4°. Moreover, the solar radiation can rise to 1600 kWh/m² per year. The temperature rarely goes far below zero Celsius, the winter conditions nonetheless require non-negligible heating systems for the comfort. On the other hand, in summer, the high humidity and temperatures (often rising over 25° Celsius from June to August) require an equally important cooling load. As the air flow rate through the year is not adequate to provide natural ventilation, special attention for cooling and heating loads is necessary. Conventional design methods of passive techniques such as shading devices like horizontal shades, Venetian blinds and screens were historically used especially in south facades to reduce the sun exposure, provide adequate daylight and to reduce the glare probability. The concerns in using this kind of shading device are that it doesn’t implicate the view factor to outside as a driving force for the design. Therefore, a trade-off between the different measures has to be reached in order to achieve a visual comfort and preserve the view of the surrounding alpine landscape. This paper discusses the relation between the two parameters (daylight and view) by applying daylighting and glare analysis as well as view assessment of different shading devices.
PREVIOUS WORKS

Shading devices were historically used to reduce the negative effects of direct sunlight and solar radiation inside buildings during cooling period and to permit heat gains during heating (Platzer, W.J., 2001). The impact of using traditional shading devices such as horizontal louvers and solar screens on daylighting, energy use and thermal comfort was studied by several researchers in different locations and climates. Yoo S, et al., (2011) investigated the usage of fixed shading devices on decreasing the thermal loads in addition to increasing the visual comfort and decreasing the glare, and, it was found inevitable to use it on the south facades, especially in Mediterranean climates. In a similar approach, Datta G. (2001) studied the thermal performance of a building with external fixed horizontal louver with variable slat lengths and tilts. LIGHTSCAPE software and PHOENICS Computational CFD package for natural ventilation were used by Hien and Istiadji (2003) to study the effects of 6 different shading device types on thermal comfort in a residential building in Singapore. Hammad and Abu-hijleh (2010) analyzed the energy consumption of external dynamic louvers integrated to office building’s facade in Abu Dhabi. The impact of using different shapes of solar screens on daylighting and energy performance in hot arid climate was investigated by Sherif et al. (2012). Parametric and generative design tools allowed the creation of shading devices with a higher degree of geometrical complexity. El Ahmar et al., (2015) used a double skin facades inspired from nature to design a porous and folded façade for reducing cooling loads while maintaining daylight needs of office buildings in hot climatic regions. The possibilities of different arrangements of folded modules had been also examined to create environmental efficient kinetic morphed skins, to achieve different Kinetic origami-based shading screens categorized parametrically to provide suitable daylighting (El Ghazi et al. 2014).Kirimtatt et al., (2016) conducted a review of previous research work that utilized simulation modeling to analyze the impact of shading devices. More than a hundred paper were analyzed and organized by simulation type. Different types of simulation analyses were studied including the overall energy performance, daylighting, natural ventilation, indoor thermal and visual comfort among many others. However, it can be noted that only a few studies considered the view as one of the main objectives of shading devices design (Tzempelikos A.(2008), Kim & Kim (2010), Sherif et al. (2016)).

View to the outside is more than often left out during design, despite the undoubted importance of view and effects on users (Leather et al., 1998; Heschong Mahone Group, 2003), Hellinga and Hordijk (2014) attributes this to the reasons that research on daylighting and view quality belongs to different research discipline and secondly, there is usually very limited time and budget for architects and engineers to work on daylighting and view. Hellinga and Hordijk also found that users prefer distant and nature views and views that contain water. In design cases were view is an essential concern, such as spaces overlook-
ing important landmarks or natural features, such as the case presented in this paper, view to the outside cannot be neglected. This paper, therefore, tries to answer the question of How to design a shading system that ensures excellent daylight performance with minimum sacrifice of the view? In the design, utilizing computational and parametric tools to evaluate and optimize the shading systems for daylight and view quality.

**METHODOLOGY**

**PARAMETRIC MODELLING**

A parametric model for the multi-functional building was created using the Building Information Modeling software Revit. In order to have a greater control on the design parameters, the model was then exported to, and modified by, a visual programming language for parametric design Grasshopper. The investigated space, which is located on the top floor of the building, had the dimensions of 7.5 m x 20.0 m with 3.3 m ceiling height. Different types of shading devices were investigated for the daylighting performance, glare probability and view to outdoors. The performances of five shading devices were examined: horizontal shadings, vertical shadings, egg crate, an external diagrid structure, and an external diagrid structure with an overhang. For each of these shading devices, the impact of changing the vertical (or horizontal) shading angle was studied. The impact of changing the eggcrate thickness and spacing for the dia-

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**Table 1**

<table>
<thead>
<tr>
<th>Shading type</th>
<th>Parameters</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal shading</td>
<td>Vertical Shading Angle (VSA)</td>
<td>20° to 50° with a step of 5°</td>
</tr>
<tr>
<td>Vertical shading</td>
<td>Horizontal Shading Angle (HSA)</td>
<td>20° to 50° with a step of 5°</td>
</tr>
<tr>
<td>Eggcrate</td>
<td>Vertical Shading Angle (VSA)</td>
<td>20° to 50° with a step of 5°</td>
</tr>
<tr>
<td></td>
<td>Thickness</td>
<td>2.5 to 12.5 cm with a step of 2.5 cm</td>
</tr>
<tr>
<td>Diagrid structure</td>
<td>Vertical Shading Angle (VSA)</td>
<td>20° to 50° with a step of 5°</td>
</tr>
<tr>
<td></td>
<td>Number of Modules (Spacings)</td>
<td>6, 12, 18, 24 and 30 Modules</td>
</tr>
<tr>
<td>Diagrid structure + overhang</td>
<td>Vertical Shading Angle (VSA)</td>
<td>20° to 50° with a step of 5°</td>
</tr>
<tr>
<td></td>
<td>Number of Modules (Spacings)</td>
<td>6, 12, 18, 24 and 30 Modules</td>
</tr>
</tbody>
</table>

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**Figure 5**

Main designed shading system selected. A. Vertical louvres. B. Horizontal louvres. C. Eggcrate. D. Diagrid louvres. E. Diagrid with horizontal louvres. For each, the most effective variables were identified, represented in “modular size”, “shading angle” and “shading thickness”.
grid was also considered. Figure 1 shows an illustration of the five shading devices and their design parameters. 7 different cases for each of the horizontal and vertical shadings were studied and 35 cases for each of the other three shading devices. Overall 119 shading designs were examined. The ranges of the shading devices parameters that were examined are shown in Table 1. (see Figure 4)

**SIMULATION METHODOLOGY**

Daylighting analysis was carried out using DIVA for Rhino, which is used as an interface to Radiance and Daysim simulation engines. The criteria used for evaluating the daylighting performance was the daylight availability which was found more suitable to the studied case. The DAv divides the measuring nodes according to three criteria daylit for points that receives illuminance between 300-3000 lux for 50% of the time, over lit for points that receives >3000 lux for at least 10% of the time and partially daylit for points that has illuminance values<300 lux for more than 50% of the time. The aim is, therefore, is to increase the daylit area of the space. The analysis grid had a desk-level height of 0.80 m and spacing of 0.60 m. (see Figure 5)

Glare and view analysis were conducted for a selective viewpoint that represents a seated person (height = 1.2m), 2.0 m from the facade and facing the window. For Glare analysis Evaglare was used to measure the discomfort using the Daylight Glare Probability (DGP) index. the GDP was analyzed at 9:00, 12:00 and 15:00 on the solstice and equinox dates to cover the different sun positions. In the DGP index, glare is divided into four categories: intolerable glare (DGP > 45%), disturbing glare (45% > DGPP 40%), perceptible glare (40% > DGPP 35%), and imperceptible glare (DGP < 35%). In this study, each category was given a score number with imperceptible glare having the highest score (3 pts) and intolerable glare the least (0 pts). the Accumulative Glare Percentage (AGP) is then calculated to compare the performance of different shading designs, where the highest possible value (100%) means that only imperceptible glare occurs at all times and the least (0%) indicates that an intolerable glare can be witnessed at all times.

For the view analysis, a view factor was calculated using 3D isovist. An isovist field is defined as “. .. the set of all points visible from a given vantage point in space and with respect to an environment.” (Benedikt, M. L.1979) . In this study, the vantage point is the same one defined for the glare analysis. A 3D isovist was created for the focal area of the viewer’s field of view (see Figure 6). The ratio between the number points seen from the vantage point in each case to that without a shading device is calculated to compare between the different shading devices.

The results from the three analysis criteria, daylighting performance (DAv), Glare (AGP), and View Factor are compared to arrive at shading devices with a satisfactory performance. Acceptable values for the three criteria were assumed to be 75%, 50% and 50% for the daylight availability, accumulated glare percentage, and view factor respectively.

**RESULTS**

**BASECASE**

The unshaded facade was assumed as the basecase in this study in order to evaluate the effect of each shading device on the daylighting, glare and view performance. The basecase had a significantly low daylighting and glare performance due to the vast area of unshaded glazing in all its four facades. Due to the penetration of direct sunlight the daylit area reached only 36%, while the overlit area occupied almost two-thirds of the space. The accumulative glare
score was found to be very low with a value of 13% as an intolerable glare was witnessed in most of the cases with the exception of the morning hours. However, even at this time, a perceptible or disturbing glare was witnessed. Although the base case has a panoramic view with only the internal structure as a physical obstacle, such a high probability of glare occurrence and sun penetration would surely affect the possibility of enjoying the view.

**EGGCRATE**

Thirty-five cases of eggcrate shadings were analyzed. Almost all the cases achieved over 80% daylit area and half of the cases reached 100% daylit area. Nevertheless, unlike the horizontal and vertical shading, the eggcrate reduced the chance of glare occurrence significantly. Most of the cases had an acceptable cumulative glare percentage and in few cases the AGP reached more than 80%. This, however, came in the expanse of the view performance. With the eggcrate cells causing a significant obstruction to the view, the view factor was found to be unacceptable in most of the cases. Only cases with very small thickness (high perforation ratio) and small extrusion achieved acceptable view factor. However, in these cases, the glare performance was at its lowest values and was below the acceptance threshold. Only one case achieved an acceptable performance in all the three criteria which had a thickness of 2.5 cm and 35° shading angle.

**HORIZONTAL AND VERTICAL SHADINGS**

The horizontal shading devices enhanced the daylighting performance greatly were most of the cases had over 90% daylit area percentage, in comparison to just 36% in the base case. The glare analysis, however, showed a high probability of glare occurrence and only one case achieved an AGP higher than 50%. The impact on the view was, however, better than anticipated with only between 17% to 27% of the view obstructed. Cases with larger extrusions (higher shading angles) had a better daylighting and glare performance while cases with smaller extrusions had a better view factor.

In contrary, vertical shadings provided a poor but mostly acceptable daylighting performance. The daylit area percentages ranged between 49% with a Horizontal shading angle = 20°, and 60% with HAS= 50°. Glare analysis also showed a high probability of glare occurrence all year round with a maximum cumulative score percentage of 36%. Nevertheless, the view factor was also found acceptable in all the cases with a maximum view factor of 87% and a minimum of 64%. Figures 7 and 8 show the daylighting, glare and view performances of the horizontal and vertical shadings.

**DIAGRID STRUCTURE**

All the 35 cases of the external diagrid structure had a good impact on the daylight performance with a minimum daylit area percentage of 76% and nearly half of the cases with 100% daylit area. Similar to the egg crate, the diagrid structure also enhanced the visual comfort significantly as the glare probability decreased and the AGP reached 100% in several cases. The external view also showed satisfactory performance with a maximum of 85.54% and most of the cases with view factor higher than 50%. Nine different cases achieved a satisfactory performance in all three areas of analysis. Figure 10 shows the performance of the diagrid cases. Cases with acceptable performance in all of the three criteria are highlighted.)
**DIAGRID WITH OVERHANG**

This unique shading solution aimed at combining the positive impact of both horizontal and diagonal shading devices. Once more, 35 different configurations were tested. It succeeded in achieving notable improvements in all of the three criteria. Daylighting performance achieved more than 90% daylit area in all cases with most cases having a 100% daylit area percentage. Glare probability also improved as almost all of the cases had an acceptable performance and AGP reaching 100% in few cases. While not all the cases had a satisfactory view performance, in many cases the view factor had an acceptable value and reached a maximum of 86%. In many cases the daylighting, glare and view were found to have acceptable and significantly improved performances. One notable case was with 45° shading angles and 6 modules of diagrid external structure, where daylit area percentage reached 100%, AGP of 75% and view factor of 71%. Overall 14 different configurations achieved an acceptable performance in all the three criteria.

Figure 9
Daylighting, glare, and view performances for the Eggcrate, Diagrid, and diagrid with overhang shadings. The cases with satisfactory performances are highlighted.

Figure 10
Glare performance at 12:00 on 21 June for the base case and four different shading configurations.

<table>
<thead>
<tr>
<th>Shading system</th>
<th>Base case</th>
<th>Horizontal shadings</th>
<th>Egg crate</th>
<th>Diagrid</th>
<th>Diagrid and overhang</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Glare</strong></td>
<td><img src="image1.png" alt="Glare" /></td>
<td><img src="image2.png" alt="Glare" /></td>
<td><img src="image3.png" alt="Glare" /></td>
<td><img src="image4.png" alt="Glare" /></td>
<td><img src="image5.png" alt="Glare" /></td>
</tr>
<tr>
<td><strong>Parameters</strong></td>
<td>No shading system</td>
<td>VSA = 50°</td>
<td>Shading thickness = 2.5 VSA = 35°</td>
<td>No. of module = 18 VSA = 30°</td>
<td>No. of module = 6 VSA = 45°</td>
</tr>
</tbody>
</table>
Figure 9 shows the daylighting, glare and view performances for the eggcrate, diagrid and diagrid with overhang. The cases that achieved an acceptable performance in the three criteria are highlighted. Figure 10 shows the impact of the different shading devices in comparison to the basecase on the glare performance.

DISCUSSION AND CONCLUSION
This paper presented and discussed a design approach for designing building facades that overlook exceptional scenery and views, which requires special care not to obstruct the view to the outdoors. Nevertheless, poor shading design can usually result in high solar penetration and glare probability affecting the ability of the users to enjoy the outdoor view. In this study, 119 different configurations of five shading types were investigated. Overall, 25 different configurations from 4 types of the shading devices achieved a satisfactory performance for daylighting, view and glare. The combined shading of an external diagrid structure and a horizontal overhang offered the best performance with 14 cases, followed by the diagrid shading and eggcrate and horizontal shadings. For future work, and depending on the case study other aspects such as energy consumption, Life Cycle Analysis, and Life Cycle Cost could be included in the framework.

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