Kinetic Shading System as a means for Optimizing Energy Load

A Parametric Approach to Optimize Daylight Performance for an Office Building in Rome

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Current research, as a part of on-going PhD research, explores the possibilities of dynamic pattern inspired from biomimetic design and presents a structured framework for light to manage strategies. The experiment stresses the improvement of daylight performance through the design and motion of kinetic facades using various integrated software. The impact of kinetic motion of hexagonal pattern was studied by integrating triangle and triangle covering through blooming pyramids on south-facing skin to control the daylight distribution, using a parametric simulation technique. The simulation was carried out for a south oriented façade of an office room in Rome, Italy over three phases. The first optimized results represent the static base case, which were compared to the other two proposed dynamic models in this research. Results demonstrate that dynamic façade achieved a better daylighting performance in comparison to optimized static base case.

Keywords: Bio-Inspired Pattern, Parametric Design, Dynamic Façade, Daylighting

INTRODUCTION
Architecture and its dynamic facilities are important ways to actively respond to variable ambient conditions and requirements while also meeting the needs of occupants and addressing issues of building performance. Within contemporary architecture, there is a growing interest in motion buildings and their components are gradually shifting from static to dynamic to improve performance and occupant satisfaction (Goia et al., 2013). A dynamic ‘filter’- the envelope- between interior and exterior unquestionably allows for a desired change in building use or a rapid adaptation to new ambient conditions only through its modification. Moreover, mechanical shading device systems allow not only light, view, sound, or smell to be filtered, but also a ‘filter’ motion that can also enhance aesthetic architectural experiences (Mahmoud, A. H. A., & Elghazi, Y., 2016). A building façade plays a vital role in reducing artificial lighting and heat transfer by improving precise control over the use of natural light in interior spaces. To obtain appropriate natural lighting for indoor work
spaces, much research has been conducted and current technology focuses heavily on optimizing the architecture composition of façade properties opening. Hence, parametric design and a computer simulation prepare the grounds for a research to generate dynamic facades and evaluate it in accordance with daylight transmittance in the early design stage (Goia et al., 2013). Contemporary office building facilities require tremendous energy consumption to meet the comfort level needs of their users, and that results in adopting active technologies such as lighting and HVAC systems. Biomimicry’s inspiring design has become a promising approach, as it provides different design alternatives that attain adaptability of the environmental concerns (Mahmoud, A. H. A., & Elghazi, Y., 2016). While the type of office building is used as a particular illustrative case study for the on-going PhD research, a part of it is used in this research paper (Jahanara and Fioravanti, 2016). Here, the biomimicry and parametric design process for designing a kinetic pattern are point out which are formed by multiple singular movements through the lens of morphology. The proposed bio-design approach has been employed as a prototype to generate an adaptive dynamic façade in relation to daylight. This paper explores the possibilities of kinetic composition afforded by geometry’s façades in motion. Composition is analysed in terms of pattern, being defined as the relative movement of individual kinetic parts in time and space - the way in which multiple singular kinetic events cluster, or propagate across a façade, over time. That exploration results a better understanding of adaptations in relation to the organisms, their environment and biological mechanism. In addition, the study explores dynamic façade that parameterises and evaluates its performance in regards to integrating motions as a response to dynamic day lighting.

**BIOMIMETIC STRATEGY FOR MANAGING LIGHT**

Biomimetic brought about a design approach that applied nature as a guide for innovation technologies which carry out the future of building facades. It represents an innovative alternative that reconciles energy efficiency with integrating adaptability that responds to high-quality indoor climates needs. Therefore, innovative techniques in constructions and designs are now offering more adaptive facades that respond and ‘behave’ as a living organism to their environmental context (Goia et al., 2013). Efficient light management is necessary as a design requirement aspect of building’s facades that are exposed to solar radiation. Taking biomimetic-living organisms, as design solutions for buildings, is a unique strategy to manage light: it is a design framework that facilitates the selection of appropriate strategies of nature. Not only the framework enhances the light management by elaborating on the involvement aspect which too many organisms’ nature systems can provide, but also it behaves as an analogical design development that responds to light (Fox and Kemp, 2009). Nevertheless, biomimetic is not about creating an exact replica from nature, but is about translating its functional biology aspects into the architecture in a performativity level (Goia et al., 2013). Morphological, behavioral, and physiological means influence light management efficiency strategy and its ability to manage light intensity. For instance, some plants are able to transmit light because of their intricate structural assembly, while others optimize light by solar tracking and enhancing body exposure (Goia et al., 2013). Through exploration and learning from those strategies and techniques of nature, a design discipline for a new light system management is emerging, aiming at building skins. Biomimetic design field is still in a challenge with architecture, especially with the growing integration between the biomimetic design, engineering, and material science (Fox and Kemp, 2009). In this regards, many experiments have been carried out to represent biophysical information systematically in a similar context to buildings. However, a systematic representation of building application for light management strategies is limited. Figure 1 shows schematic diagrams of Biomimetic impacts on architecture with the light management efficiency.
<table>
<thead>
<tr>
<th>Morphology</th>
<th>Behavior</th>
<th>physiological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazza Bin Zayed Stadium - UAE</td>
<td>Water Reaction -Royal College of Art - 2015</td>
<td>Pavilion - Germany Project year: 2013</td>
</tr>
<tr>
<td>Project Year: 2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stadium inspired Pattern design is the rotating fractural geometry of the date palm fronds as an outer facade. In addition, facade movement responds to the daily heat to act as a passive cooling device; shading the building during the day and allow fresh air to flow. Hence, movement depends on sensors’ respond to the daylight factors. (Archdaily, 2015)</td>
<td>Pattern inspired by a pinecone, that open and closes naturally to protect seeds from the wet weather and spread it when it is dry. That happens when outer layer expands more than the other layer which therefore causes different scales to bend and close its cone. The cone is a tile where the outer layer elongates and curves the material away when wet. (Archdaily, 2015)</td>
<td>Pavilion is a particularly interesting way in moisture-driven movement which is observed in spruce cones. This movement takes place through a passive response to humidity changes, just like plant movements from cell pressure metabolism. Hence, movement is independent with no energy consumption from the plywood sheets' metabolic function. (Archdaily, 2013)</td>
</tr>
</tbody>
</table>
Based on the schematic diagram in figure 1, this research paper is considering and underlining the environment process at initial stages of a design process, taken by the morphological strategy. Therefore, the order in nature can promote and develop adaptive solutions for building envelopes. The current paper consequently focuses on how the morphological applications of biomimetic can produce an adaptive geometry pattern which responds to the efficient design factor of the daylight.

ASSESSING BUILDING FAÇADE’S DAYLIGHTING PERFORMANCE

Daylight is the best source of light as it most closely matches the human needs. It is free and does not increase energy consumption for lighting (Li and Tsang, 2008). Accordingly, a design pattern is proposed for building facades which is responsible for the amount of daylight in indoor workplaces to achieve a better performance with respect to light quality, energy consumption and occupant satisfaction. The proposed dynamic façade’s geometry is inspired from the structure of living organism responses to daylight in Lotus plant. The geometry optical structure is aiming to adapt the building to control the natural light and reduce the need of artificial lighting so to respect visual comfort and environmental concerns Nabil and Mardaljevic, 2005). The “Useful Daylight Luminance” (UDI) predictive method was then used to measure the amount of natural light. The UDI method divides annual daylight illuminance in a workplace into three sections. The first one includes areas that receive less than 100 lux, which is not appropriate, and thus demand additional artificial lighting; the second section corresponds to the range of 100 to 2000 lux, which is suitable for working activity; and the last one includes illuminance exceeding 2000 lux which results in potentially visual discomfort. This method is more realistic than the conventional “Daylight Factor Approach” -DFA- which only considers a single factor (Nabil and Mardaljevic, 2005).

RESEARCH AIMS AND METHOD OF INVESTIGATION

Current research aims to create an adaptive kinetic folding pattern which highlights the significant effect of dynamic facade design on indoor daylighting quality inspired by Biomimicry. Biomimicry has become a trend in interactive architecture as an inspiring concept. It uses the organism as a successful case which is able to control and utilize energy in harsh environments. The natural organism uses minimum amounts of material to build intelligent structures so to successfully optimize its energy in reaction to the environment. The proposed design pattern in this study has also been inspired by the blooming motion for Lotus flower that mitigates over-lit conditions. There are many types of plants in nature that open their flowers and leave them under the sunlight and close them when it is dark at night (Fox and Kemp, 2009). They have a basic behaviour guided by this simple rationale that can be performed by ‘agents’. The structure scheme of the blooming shape defines the spatial design and how the pattern reacts to the sunlight. The Lotus flower’s geometry reacts to the sun by changing from a triangular shape to a hexagonal, maximizing the differences between its extended and folded states. This pattern acts as a receptive unit to control the daylight conditions, affecting occupant satisfaction while saving A.C. energy (Mahmoud, A. H. A., & Elghazi, Y., 2016). In this regard, a case study for a geometry which applied in an office building’s facade, not in an urban area, was conducted to simulate the environmental setting similar to Rome’s geographical location. Likewise, a proposed pattern was generated by integrating performance analysis tools with parametric modelling i.e. implementing Rhino and Grasshopper programs. Hence, it was determined that evaluating the office workspace conditions by means of DIVA software analyses to enhance energy saving, daylight, glare, and performance, depends on balancing these objectives,(see figure 2).
PARAMETRIC OFFICE MODEL
A side-lit office space was constructed as the base case study model for an office building located in Rome, Italy. The area is 37.31 m² and dimensions of 4.10 m width, 9.10 m depth and 3.20 m height, facing south and located at the third floor (Figure 3).

Although the façade’s configuration sets in the case study changes, the space dimensions remain the same throughout the entire study. Initially, the simulation was run for clear and overcast skies for different types of motion test. The interior surfaces were assigned a reflectance of 80% for the ceiling, 50% for walls, and 20% for the floor. The kinetic skin was made of sheet metal material. The opening was assigned a doubled-glazed material with 65% visual transmittance. The kinetic skin is an external layer of a double façade which acts as a shading screen coupled with glazed interior layer that has an in-between buffer of 35 cm, see (figure 4).

DESIGN PROTOTYPE
The concept of dynamic façade’ geometry is influenced by the adaptive behaviour of the plants and the concept of Lotus flower that reacts to the sun by changing from a hexagonal shape to a triangle one, and the triangle part being covered by a blooming pyramid. The geometry pattern has two parts: dynamic and static states are created by integrating the triangle shape into the hexagonal. The dynamic part is maximizing the differences between its extended and folded states’ receptive unit to control the daylight conditions when day lighting increases and affects the occupant satisfaction while saving A.C, see figure 5. Likewise, in the proposed design, two methods are used to operate the blooming panels. The first method is the regular plane of the dynamic blooming pyramid, (see figure 6), while the second model eliminates some blooming part to provide more visual comfort for occupant spaces and decreases the mechanical part of structure, see (figure 7).

DAYLIGHTING EVALUATION
Research work was divided into three consecutive phases to evaluate the daylight by Diva for Rhino. The case study model with the two phases of proposed pattern was then simulated. The simulation was planned to perform for four months per year (March 21, June 21, September 21, and December 21) at three hours per day (9:00 am, 12:00 pm and 3:00 pm). Those times and dates were chosen, to have a fairly accurate evaluation of the performance in the case study model for its two proposed patterns as well as the base case: a) The first simulation focuses on the analysis of delighting performance for a window with dimensions of 3.20 m width and 1.2 m height. The Window Wall Ratio (WWR) is set to 25% as the base case model, (see table 1). b) The second simulation represents a daylighting performance, using parametric tools for kinetic hexagonal geometry to a triangle, and the triangle being covered by a blooming pyramid. The blooming motion has intelligence sensors to achieve the near optimum day light.
lighting adequacy. In the case of first set A, the daylight’s assessment for the dynamic facade was simulated at three circumstances: when the assemblies are closed, partly open and fully open, see (table 2).c) The third stage of the simulation represents the dynamic facade’s pattern set B. The blooming pyramid’s geometry was assigned according to the visual work space comfort, see (table 3).

**DAYLIGHTING SIMULATIONS - RESULTS**

As mentioned, Grasshopper Simulation for Diva to assist the day lighting performance was used in plan-
Grasshopper simulation was used to identify the parameters and inputs for the proposed model and set up the evaluation criteria for the daylighting assessment. Then Diva was applied to simulate the process of daylighting and send the results back. Daylighting requirement was set to three illumination evaluation levels for the floor area: "daylit", "partially daylit" and "overlit" areas. The "Daylit" area achieves illuminance levels between 100 lux and 2000 lux for the floor area; "Overlit" area achieves illuminance greater than 2000 lux for the floor area with potential glare; and "Partially lit" area achieves illuminance below 100 lux for the floor area. The simulation parameters were set to measure daylight illuminance sufficiency for the room. Diva parameters were set to calculate the percentage of analysis points that achieves illuminance levels between 100 lux and 3000 lux.

In this stage, the base case was evaluated for daylighting adequacy in summer; nearly half of the base case floor area was found to be "daylit". However, the

<table>
<thead>
<tr>
<th></th>
<th>Base case</th>
<th>21st March</th>
<th>21st June</th>
</tr>
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<tbody>
<tr>
<td>21st September</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21st December</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9:00 12:00 15:00 9:00 12:00 15:00
other half of the floor area has been “overlit” which causes problems with visualization and glare. On the other hand, in winter, the “overlit” was relatively high and nearly less than half of the area was found to be in “daylit” area, while the other half was divided into “overlit” and “partially daylit” areas.

This means that in case of using traditional windows, only 50% of the space has adequate daylighting for most of the year. These results of daylighting performance for the proposed dynamic geometry’s sets (A), indicate that a recommended dynamic façade as a shade device improves the daylighting conditions in the workspace. In all kinetic geometries cases results were acceptable and the required daylighting was achieved better than the base case.

The results showed that in the summer, the “daylit” area was significantly increased and there was a relative decrease in the “partially daylit” area, while in winter time, only the “daylit” area was increased. In the case of selected net for the proposed blooming’s geometry, set B, represented the best daylight performance see in table 4 below.

The proposed blooming geometry cases were found acceptable at all times where “daylit” percentage reached 99% of the space at the value ranges in June, the closed and the totally opened geometry, in both case study sets, gave the most appropriate “daylit” area.

While, the partially opened geometry in both the case study sets, increased the “daylit” to almost 100% in March and September (table 2, 3).

In case study set A, the daylight performance was only achieved at opened and partially opened geometries of 95% in the winter. Hence, some acceptable results where the “daylit” area percentage that was achieved at 12:00 pm to be 93%, and its performance in afternoon at 3:00 pm, while it was slightly low in the early morning, see (table 4).

In general, results indicate a significant impact of the geometry pattern’s parameters and types of geometry organization on the overall daylighting performance in the workspace. The proposed model coupled with the two proposed organizations of dynamic skin improved the daylight performance. The blooming geometry acts convincing as a dynamic shading device to control the excessive daylight level. It is also clear that the “overlit” area was relatively improved in winter time and was mainly concentrated at four working hours of the day.
Table 4  
Floor area achieved illuminance levels between 100 lux and 3000 lux; Source: Alireza Jahanara

<table>
<thead>
<tr>
<th>Month</th>
<th>Opening/motion</th>
<th>Hour</th>
<th>Base Case</th>
<th>Case A</th>
<th>Case B</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>closed</td>
<td>9 a.m</td>
<td>88.4%</td>
<td>100%</td>
<td>97.10%</td>
</tr>
<tr>
<td></td>
<td>partially</td>
<td>12 p.m</td>
<td>88.80%</td>
<td>85.40%</td>
<td>98.80%</td>
</tr>
<tr>
<td></td>
<td>fully opened</td>
<td>3 p.m</td>
<td>89.20%</td>
<td>97.10%</td>
<td>93%</td>
</tr>
<tr>
<td>March</td>
<td>closed</td>
<td>9 a.m</td>
<td>88.40%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>partially</td>
<td>12 p.m</td>
<td>84.60%</td>
<td>91.80%</td>
<td>93.60%</td>
</tr>
<tr>
<td></td>
<td>fully opened</td>
<td>3 p.m</td>
<td>90.80%</td>
<td>95.30%</td>
<td>93.50%</td>
</tr>
<tr>
<td>September</td>
<td>closed</td>
<td>9 a.m</td>
<td>80.40%</td>
<td>100%</td>
<td>98.20%</td>
</tr>
<tr>
<td></td>
<td>partially</td>
<td>12 p.m</td>
<td>80%</td>
<td>90%</td>
<td>98.80%</td>
</tr>
<tr>
<td></td>
<td>fully opened</td>
<td>3 p.m</td>
<td>88.20%</td>
<td>93.60%</td>
<td>99.90%</td>
</tr>
<tr>
<td>December</td>
<td>closed</td>
<td>9 a.m</td>
<td>88%</td>
<td>99.40%</td>
<td>98.40%</td>
</tr>
<tr>
<td></td>
<td>partially</td>
<td>12 p.m</td>
<td>70%</td>
<td>97.70%</td>
<td>99.40%</td>
</tr>
<tr>
<td></td>
<td>fully opened</td>
<td>3 p.m</td>
<td>75%</td>
<td>99.40%</td>
<td>100%</td>
</tr>
</tbody>
</table>

DISCUSSION & CONCLUSION

The research paper presents a bio-inspired geometry design driven by daylighting performance as a design factor for office workspaces in Rome, Italy. The proposed blooming geometry pattern was parametric by Rinho and simulated by Dive 4.0 to control daylight uniformity.

The geometry prototype was designed as a responsive dynamic system inspired by mimicking Lotus plant’s response to light. The adopted methodology can therefore be interpolated for the annual daylighting performance of a dynamic geometry which can be used to generate various geometry motions using parametric exhaustive search. Moreover, the research experimented the idea of selecting partially opened dynamic pattern configuration and static part configuration for less material aligned with the daylight and visual comfort design factors. These types of configurations allowed for the different application purposes: closed for privacy, open for external visual interactions, and partially open to shade in “overlit” hours. Therefore, a full annual simulation gives a better guide to improve the pattern organization and its geometry parameterizes daylighting optimization for the space performance.

Running the simulation, hence, represented a year-round performance for the same blooming geometry motion in different sets of organizations. In order to trace the daily, hourly, and then monthly and annually facade responses to climate changes for testing the unusual luminance level, the bio-inspired geometry was improved as a dynamic screen. It is also suggested a further research and more exploration should be done to discuss the daylight as a parametric, yet a design target, which is going to be covered in the on-going PhD research. In addition, a physical fabrication mock-up for the geometries façade can indeed give another depth to the study. The ongoing research of the PhD has a potential to become a basis for the future intelligent and adaptive dynamic patterns that respond to the daylight parameters, aiming to optimize the energy consumption and occupant visual comfortable. Furthermore, it will provide the daylight design factor as a framework to understand the responsive dynamic façade and optimize the office buildings’ energy performances aligned with improving the indoor workspaces’ comfort conditions.
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