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Responsive skins as a mean to daylight harvesting in patient's room in region with hot and arid climates

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ABSTRACT/RESUME

Abstract: *Nowadays architects and engineers are challenged to design an environmentally conscious architecture, aiming to minimize greenhouse gas emissions and energy consumption. The strategy of daylight harvesting is one of the most important requirements ensuring thermal and visual comfort conditions and to minimize energy consumption in buildings in regions with hot and arid climates.*
Daylighting has a significant effect on healthcare outcomes. Its positive effect on physiological and psychological human health (staff and patients especially who are bedridden) justify its importance to be considered as the most important physical aspect in the healing environment creation. Most healthcare settings in regions with hot and arid climates are designed without proper consideration of daylighting principles, where healthcare staff, patients and visitors are impacted on negatively when natural light is either excessive or lacking.
Through this research, we are aiming to examine the daylight harvesting effectiveness through the introduction of a responsive shading device in South-East faced patient's room façade located in a region with hot and arid climates. A quantitative approach is adopted to evaluate the performance of the proposed system by using computer simulation. Through the experimentation results, we conclude that the natural light access in the patients' room is improved and optimized.

I. Introduction

With the advent of global warming, present and future architects are challenged to design buildings that minimize greenhouse gas emissions, energy emissions and energy consumption [1, 2]. One sustainable strategy used to minimize these factors is daylighting of the interior spaces, which can be most effective in arid regions to reduce global warming [3].
Lighting can affect the health of people in buildings [4]. This goes beyond the safety aspects of providing enough illumination to see by; lighting affects mood and human circadian rhythms [5]. Poor lighting can cause glare, headaches, eyestrain, skin conditions and various types of sight loss. It is important for designers, building owners and occupants to be aware of these issues [6, 7]. Studies on daylighting has always focused on schools, offices and commercial buildings despite it is having a more profound effect on healthcare buildings more than any other building especially for those who are bedridden [8, 9]. Healthcare settings are typically considered heavy energy consumers due to high internal loads [10, 11]. This is exacerbated in arid regions, due to the excessive cooling loads that result from the intense solar exposure.
Designing for health is backdated to a long time ago, however it was treated in diverse methodologies and was termed as alternative or complementary medicine affecting both staff and patients wellbeing [12, 13]. Design guidelines require the provision of

external windows in these spaces [14, 15]. These provide daylighting and access to external view [16], yet at the same time increase solar penetration in the harsh arid environment [17, 18]. Careful design of the window and their shading systems can help in reducing the total energy loads without detriment effect on visual comfort [19]. Scientific researchers have revealed that visual simulation of nature, natural lighting, artwork, relaxing colors and therapeutic sound can greatly accelerate the therapeutic process and create a less stressful healthcare premises [20, 21, 22, 23, 24].
This study focuses on investigating the daylighting harvesting of a proposed dynamic building's skin, in South-East facing patient's room using Rhino as a modelling tool, Grasshopper as a parametric interface and Diva for daylight evaluation, where the effects of external climatic conditions in the city of Biskra, region with hot and arid climate, are treated. The bioclimatic analysis of the city of Biskra indicates that most of the year lies outside the thermal comfort zone (only 20.5% of the year is in comfort). The strategy of protection of direct solar radiation is one of the most popular requirements to approach thermal comfort conditions [25] and to minimize energy consumption in buildings in this region during the summer period [26, 27].

II. Materials and methods

The authors hypothesize that the integration of the proposed dynamic facade as a mean of solar control increases the energy efficiency of a healthcare building and allows the enhancement of the daylighting in the patient's room.
A quantitative approach is used in this research, where an experimental study using digital simulations are proceeded, in order to evaluate the performance of the proposed system aiming to verify and validate the hypothesis cited previously.
The evaluation of the daylighting performances of the studied case was treated by Diva for Rhino software. Series of simulations were conducted as part of the evaluation of the effect of dynamic facades on the visual comfort of healthcare premises. These simulations aim to show the influence of intelligent responsive shading device on buildings with glass facades.
Figure 1 presents the proposed experimental method and workflow.

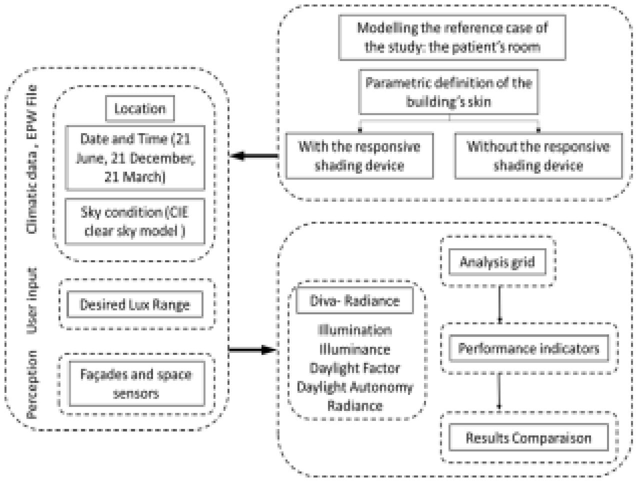

Figure 1.*The proposed experimental method and workflow*

II.1. Basic geometric model: Patient's room

The case of the study is a patient room, which is located in Biskra, and its geometry is rectangular with dimensions of 8.30m * 5.50m and with a height of 4.00m. The window facing South-East it is 3.00m and 1.40 m height and from the bottom of the window to the floor is 0.85m (see Figure 2).

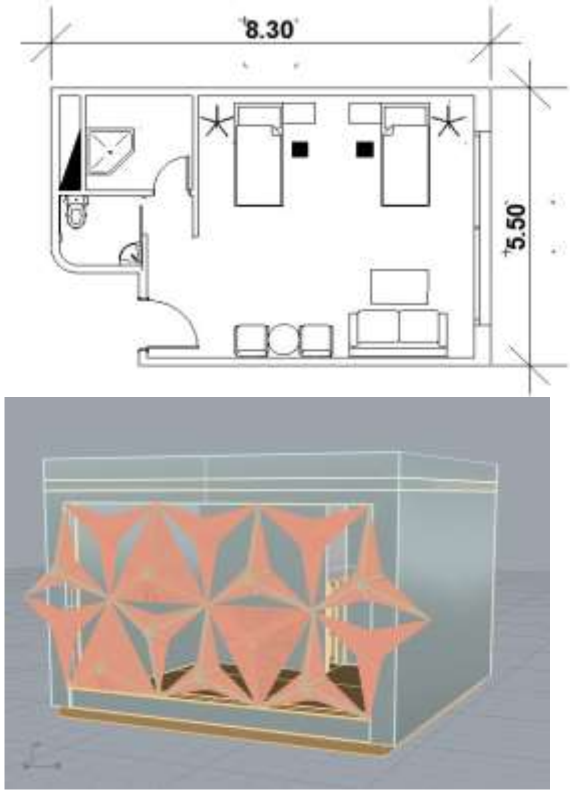

Figure 2.*The proposed patient's room: basic geometric model.*

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II.2. Simulation procedure

The shading device must respond to particular environmental conditions at its location. For the purpose of this case study, Biskra, region with hot and arid climate, and its weather file were used for the analysis. The tool was developed as a parametric model in which variable geometries are defined with associated constraints. The 3D model and components were then actuated through the algorithm simulating the shading system configurations. The design of the shading system originated in Grasshopper. All variables for our proposal alterations were defined; its geometry was connected to the daylighting analysis component DIVA, which uses Radiance as the daylighting calculation engine.

This method allows the rapid visualization of the daylight of the design model where multiple design variants for daylight can be easily tested without manually exporting to multiple softwares. DIVA was chosen so that all modelling and daylight simulations could be carried out within the Rhino and Grasshopper environments for the prediction of various illuminance calculations using sun and sky conditions derived from standard meteorological datasets.

The model's surface reflectance are 20% for floor, 90% for ceiling, 50% for walls, and 80% for glass. The orientation South-East is tested to examine the performance of the proposed shading device design. Modelling and daylight calculations of illuminance are employed in diva for Grasshopper for solstices and equinoxes. CIE clear sky model is chosen

An algorithm was employed in this parametric study to examine the advantages of using this shading device system for improving the daylighting performance in patient's room. A horizontal group of nodes was generated, for the illuminance measurements, located 0.90m above the floor covering 100% of the room area (the reference plane on which daylighting performance was simulated was the patient bed level plane (0.90 m height)). All surfaces, materials and nodes were defined and linked to the DIVA plug-in for Illuminance analysis. The simulation results of the illuminance, daylight factor, daylight autonomy and the radiation maps are presented in the tables (Table 1 and Table 5).

II.3. Parametric definition of the dynamic shading device

Using parametric design, a three dimensional geometric façade configuration, inspired by traditional mashrabiya (see Figure 3), was developed and integrated with horizontal and vertical louvers system that are proposed as a shading device (outer skin) for the case study. This system have the capability to change its configurations in response to the surrounding environment based on a desired predefined design criteria. The whole system could be fully closed when daylight is not favorable or fully opened when daylight is favorable.

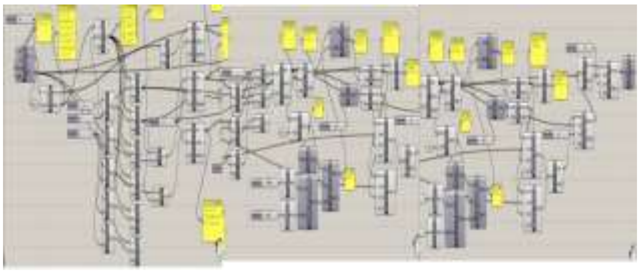


Figure 3.*The parametric definition of the proposed system*

The shading panels open and close as follows (see Figure 4):

- Maximum opening of the shade panel when it is in the shade - 100% radiation penetrating inside the building.

- Partial opening of the shade panel when it is partially exposed to the sun 25 to 50% of radiation penetrating inside the building.

- Total closure of the shade panel when fully exposed to the sun - 0% radiation entering the building.

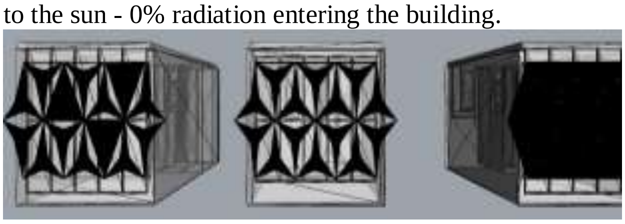
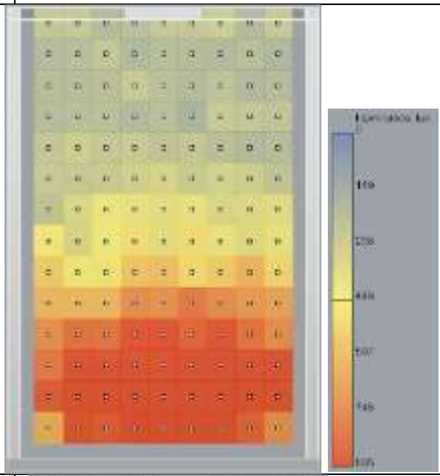
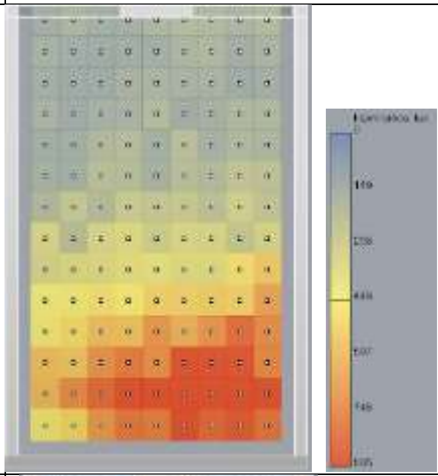
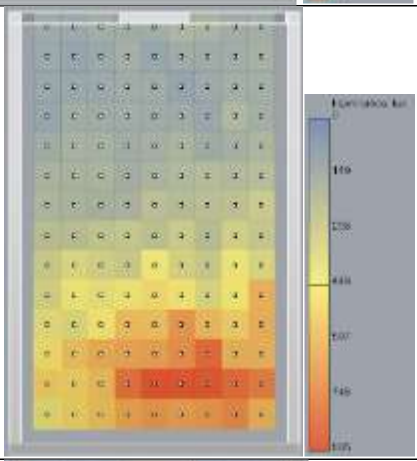
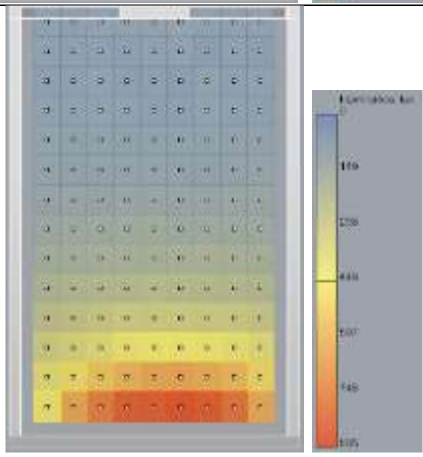
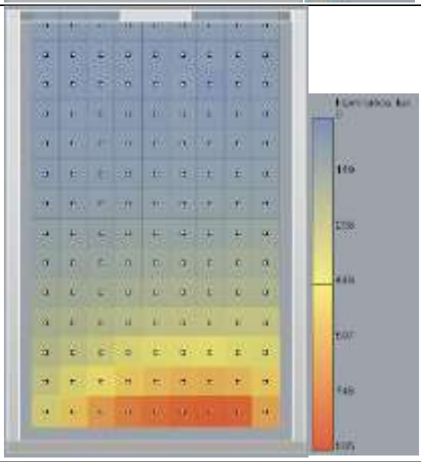
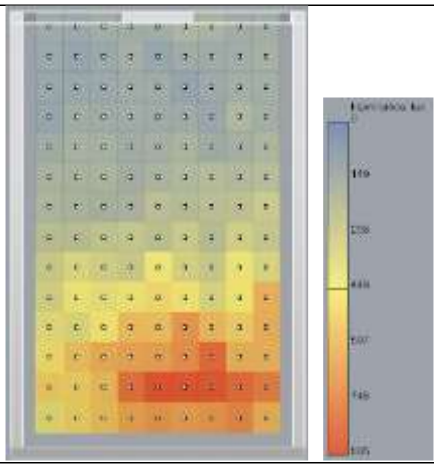


Figure 4.*The reference model in Rhinoceroes*

III. Results and discussion

Table 1 presents the simulation results of the illuminance analysis. A remarkable enhancement in the illuminance values is revealed in the case of the patient's room with the responsive shading device, where we had the ability to reach the recommended illuminance values to ensure the normal tasks in the patient's room in the region of Biskra.

Table 1. *Patient's room Illuminance (Lux) analysis*

Simulation days	Subject area "Without shading device"	Subject area "With shading device"
March 21st		
June 21st		
December 21st		

The illuminance levels of the subject area on clear sky within the range of 200-500 lux are presented in tables (Table 2, 3 and 4) where:

-On March 21st: In the case of the patient's room with the proposed responsive shading device, 60% of the area was between 200 and 500 lux. In the subject area, 26% of the area had more than 500 lux while 14% of the area had less than 200 lux with clear sky. On the second case where the subject area is introduced without the shading device, 52% of the area was between 200-500 lux, 32% of the area received illuminance level above 500 lux and 16% of the area received illuminance level less than 200 lux (Table 2).

Table 2. *Illumination level for March 21st on clear sky condition*

Illumination level	Percentage of the Subject area "without shading device" %	Percentage of the Subject area " with shading device" %
200- 700	52	60
Above 700	32	26
Below 200	16	14

- On June 21st: We observe that with the presence of proposed responsive shading device, 62% of the area was between 200 and 500 lux. In the subject area, 8% of the area had more than 500 lux while 30% of the area had less than 200lux with clear sky.

On the same day and without the responsive shading system, 68% of the area was between 200-500 lux, 13% of the area received illuminance level above 500 lux and 19% of the area received illuminance level less than 200 lux (see Table 3).

Table 3. *Illumination level for June 21st on clear sky condition*

Illumination level	Percentage of the Subject area "without shading device" %	Percentage of the Subject area " with shading device" %
200- 700	68	62
Above 700	13	8
Below 200	19	30

-On December 21st: With the proposed responsive shading device, 67% of the area was between 200 and 500 lux. In the subject area, 22% of the area had more than 500 lux while 11% of the area had less than 200lux with clear sky.

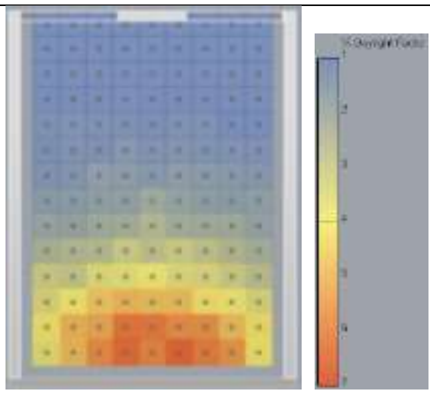
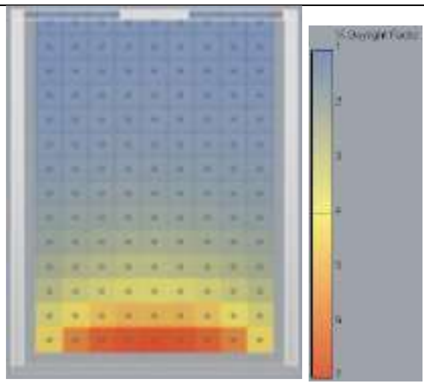
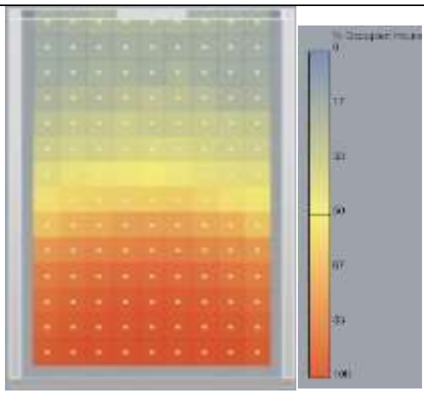
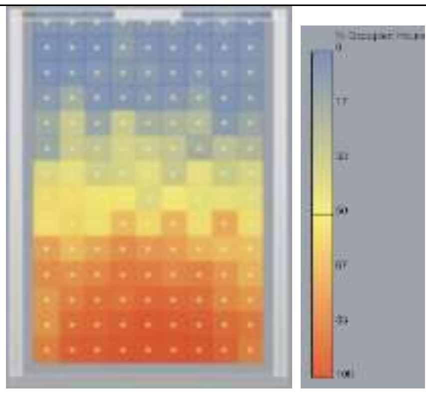
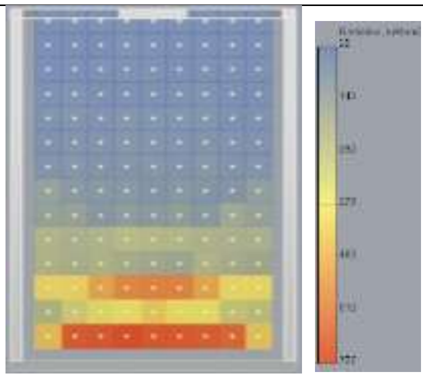
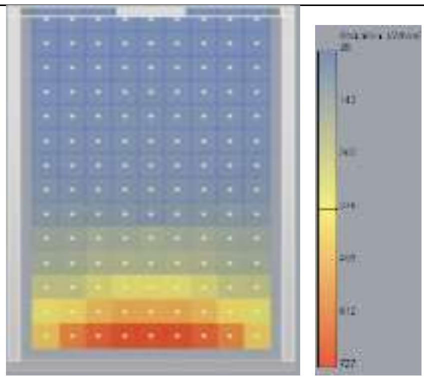
On the same day and without the responsive shading system, 65% of the area was between 200-500 lux, 7% of the area received illuminance level above 500 lux and 28% of the area received illuminance level less than 200 lux (Table 4).

Table 4. *Illumination level for December 21st on clear sky condition*

Illumination level	Percentage of the Subject area "without shading device" %	Percentage of the Subject area " with shading device" %
200- 700	65	67
Above 700	7	22
Below 200	28	11

Concerning the daylight autonomy (DA) and Daylight Factor (DF), we distinguish (Table 5):
-In the case of the model without the shading device, about 50.8% of the studied area had a DA of 300 lux value for more than 50% of the occupied hours, where 68% of all illuminance sensors have a daylight factor of 5.2%.
- For the second case of the study (with the shading device), 46% of the space has a DA of 300Lux value for more than 50% of the occupied hours, where 38% of all illuminance sensors have a daylight factor of 2%. 8759 hours per year has been considered as the total occupied time of the year.
From the radiation maps (Table 5), we distinguish an enhancement of the solar penetration in the second case, which is favorable in such climatic context in terms of thermal comfort.
Following the remarkable results obtained by simulation, it turns out that the proposed shading device can be considered as a passive process to ensure the visual comfort in patient's room. The operation of the responsive shading device is directly dependent on the solar path. The comparative study of the two patient's room, without shading system and with the dynamic shading system shows a performance gap that allows considering an optimal solution meeting the standard of visual comfort.

Table 5. *Daylight Factor, Daylight autonomy and radiation maps results among the occupied period*

Simulation days	Subject area “Without shading device”	Subject area “With shading device”
Daylight Factor	 • Mean DF : 5.2% • Occupancy: 8759 hours per year 68% of all illuminance sensors have a daylight factor of 5.2%	 • Mean DF : 2.0% • Occupancy: 8759 hours per year 38% of all illuminance sensors have a daylight factor of 2%
Daylight autonomy	 50.8% of the space has a sDA of 300Lux value for more than 50% of the occupied hours.	 46% of the space has a sDA of 300Lux value for more than 50% of the occupied hours.
Radiation map		

IV. Conclusion

In arid environments, solar radiation is the most important feature to consider when designing architectural or urban design, because direct solar radiation is intense on the facades and on the roof.

In this research, we proposed a responsive shading device for further application in the patient's room façade. The proposed system have the capability to change its configurations in response to the surrounding environment based on a desired predefined design criteria. The whole system could be fully closed when daylight is not favorable or fully opened when daylight is favorable.
A quantitative approach is used, where an experimental study using digital simulations are proceeded to evaluate the performance of the proposed system. The results of the experimentation demonstrated the need for a careful consideration of the used shading device system and openings in relation to different patient room designs. The use of responsive shading systems was found to be essential in providing acceptable daylight harvesting and energy saving. This strategy solved the problem and gave optimized indoor daylight performance in terms of illuminance, daylight factor and daylight autonomy which reached the recommended values.

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