DAYLIGHTING IN HOSPITAL PATIENT ROOMS: PARAMETRIC WORKFLOW AND GENETIC ALGORITHMS FOR AN OPTIMUM FAÇADE DESIGN
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ABSTRACT
Daylighting and access to external view in hospital patient rooms can positively contribute to patients’ healing and improve staff performance.

This paper introduced a parametric workflow and optimization for generating and evaluating alternative façade configurations. The approach developed in this study manipulated the external wall façade at efficient inclination angles and changed window distribution for the optimization of daylighting of a south oriented patient room under the desert clear-sky of Cairo, Egypt. Grasshopper, a parametric modelling tool was used to automate the daylighting simulation process. Daylight analysis was performed by the use of Diva-for-Rhino plugin via integration with Radiance and Daysim software. A genetic algorithm was used to generate and evaluate the performance of the most successful solutions by automatically adjusting different variables through control nodes until near optimum solutions were reached.

Results demonstrated that parametric workflows and optimization can be effectively used to generate unconventional patient room façade designs that provide superior daylighting performance. The approach proposed in this study produced a wide range of unconventional façade designs that achieved 100% daylight area on both the bed area and the room area, with 0% of partially-daylit and over lit areas.

INTRODUCTION
The Hospital patients’ rooms are crucial to patient observation and treatment. Daylighting and external view can contribute significantly to patients’ healing, and help reduce pain and length of stay in hospitals (FGI, 2010). For optimal daylighting performance, the external façade should be designed to maximize daylighting to assist in patient’s health care and comfort.

The positive daylighting contribution to healthcare was confirmed in several publications (Walch et al., 2005). Natural light could help reduce stress and fatigue while increasing effectiveness in delivering care, patient safety and overall healthcare quality (Ulrich, 1991 and Ulrich et al., 2004). Pechacek, et al. (2008) attempted to link environmental cues, such as lighting, with human performance and health in healthcare settings. Daylight Autonomy (DA) was used to simulate the probabilistic and temporal potential of daylight for human health needs. The variability of key architectural decisions in hospital room design, orientation, window size, and glazing material were studied for their impact on achieving threshold values for lighting. The results demonstrated that modest amounts of glazing could provide a high degree of circadian stimulus in certain orientations. In another study in Malaysian hospitals, a review was conducted on the effect of daylighting on healing the patients, besides reducing the artificial lighting energy consumption. The research studied the hospitals’ daylight and artificial lighting and their relation to other environmental aspects. Methodology included literature review, desktop analysis and pilot studies of hospital buildings (Aripin, 2007).

In more related research work, the influence of room shape on daylighting performance in hospital patient rooms was investigated. A patient room layout having an outboard bathroom proved to be most successful in regards to provision of daylighting in the south orientation. It provided the largest range of acceptable window opening sizes and shapes. It offered the possibility of having large size windows that offer better external view. However, the patient room layout with an inboard bathroom results in much smaller range of acceptable window configurations (Sherif et al., 2014). In another publication, optimization of window opening in a hospital patient room was conducted in a research that aimed at providing daylighting, external view, while minimizing the energy consumption. An optimization methodology was demonstrated through parametric computer simulations to determine the optimum window design in the form of window width, sill and lintel heights and shading device depth (Shikder et al., 2010).

On other hand, digital design has evolved to incorporate unique formal content and include performance based modelling that is reflected on architectural design considerations. This has led to the development of complex architectural concepts using adaptive systems and optimization of forms all dependent on mathematics (Okabe et al., 2009). Parametric modeling tools has the power to manipulate geometry and generate many variations by changing its parameters which can be done in manual or automatic way, not only logical operations or other modeling functions are the limit of parametric manipulation, the reason is parametric workflow can...
support various geometrical instances in a single model not like other linear 3D modeling tools (Salim & Burry, 2010). Parametric design tools can be categorized into two groups; the first group called associative-geometry, which characterized by mathematical associations between the 3D elements such as points, curves and surfaces. Grasshopper for Rhino and Generative Components by Bentley are the tools, which belong to this group. The second group is focused on Building Information Modeling. This group is characterized by parametric relationships between components of a building design that can across multiple disciplines without too much effort (Drogemuller et al., 2004). The parametric modelling tools have graphical and symbolic interface to process and manage the parametric geometries. However symbolic diagrams are more often used to define the logic and constrains. Grasshopper has this feature presented in various components, parameters, constraints, and associations, which can assist designers to form the logic that can be applied on different projects. Moreover, the key benefit of this parametric approach is valorized at the early design stages (Salim & Burry, 2010).

In a study related to this paper, parametric workflow was proposed to help architects find the optimum daylighting solutions for different types of buildings. A workflow, or algorithm, was developed to search for the optimal dimensions for window openings to ensure maximum daylighting provision inside a space. This parametric procedure produced precise and relatively efficient solutions, automatically without the need to export or import the 3D modelling information from different software programs (Wagdy, 2013). Another parametric optimization workflow was created to test the external and internal reflectors and ceiling geometry for a deep side lit space. This workflow used validated daylight simulation along with genetic optimization algorithm to find near optimum configurations for the reflectors that archive adequate daylighting in Cairo (Wagdy & Shalaby, 2013).

The above review demonstrated that a limited number of publications were concerned with the optimization of the geometry patient room external facades for the improvement of daylighting performance in the desert. It also provided evidence to the potential of utilizing parametric workflows and optimization in reaching façade solutions that can improve daylighting performance.

**OBJECTIVES**

This paper aims at exploring the potential of utilizing parametric workflows and optimization for the improvement of patient room design. It concentrated on the optimization of patient room external façade geometry for control of solar penetration, and thus improving daylighting performance. This was achieved through the manipulation of the external façade wall at efficient inclination angles and change of window distribution. The approach suggested in this paper could pave the way for reaching more sustainable hospital designs that suit the special conditions of desert locations.

**METHODOLOGY**

The methodology adopted in this paper aimed to show the effectiveness of utilizing the parametric approach in generating different design alternatives, evaluating and presenting their performance. This approach could lead the way to the generation of new unconventional design ideas.

**Parametric Workflow**

The workflow developed in this study started with the generation of a 3D model of the patient room using a three dimensional parametric modeler tool named Grasshopper, which is a plug-in for Rhinoceros. After the 3D model was created, materials and other simulation parameters were assigned using another plugin called DIVA, which is interfaced with Radiance and Daysim (Rutten, 2014; Solemna, 2014). Galapagos, which is a genetic optimization algorithm, was used to automate and optimize the daylighting simulations in Grasshopper (Rutten, 2013). While the simulations were running, a live connection with MS Excel was established to document the simulation results and the corresponding model parameter. This allowed for a case-by-case examination of results. The following sections provide a detailed overview of the parametric methodologies that were essential to optimize the patient room façade design.

**Room and facade parameters**

A hypothetical patient room design with a nested bathroom configuration was selected for investigation. A parametric façade was created for the tested room by dividing the outside wall into 4 equidistant vertical segments as shown in Figure 1.

![Figure 1 Hypothetical patient room plan](image)

The range of displacement for the main vertical segments was from (0 to 0.7 m). Each wall segment could be divided into 2 attached panels, if a small window fragment was required by the optimization logic. Three to four horizontal divisions were added to each wall segment. This allowed for the generation of...
a variety of façade design alternatives as shown in Figure 2.

The division process was connected to window generation algorithm, where the logic was defined to ensure that in all cases the first row of panels that close to the floor and would be unglazed. The shading system that is used to block direct sun rays was a horizontal sun breaker positioned at a 45° angle located on the top edges of the each horizontal panel, with two vertical sun breakers on both sides of the wall edges as shown in Figure 3.

For conceptualization, the parametric workflow was set up to define the control of window configuration and wall shape variations. As illustrated in Figure 3, every part of the 3D model was generated based on specific geometrical relations and constraints, therefore the design variations were accurately generated.

The room was assumed to be located on the second floor level of a hospital building in the outskirts of Cairo, Egypt, which enjoys a year-round desert clear-sky. No external obstruction was assumed to allow for all possible sun penetration angles.

Assumed room parameters and material are illustrated in Table 1. Different parametric variables of external wall inclination angle, window sizes and positions were controlled by the optimization algorithm. These parameters were modelled with their actual thicknesses to reduce the margin of error.

Daylight evaluation criteria
Testing was conducted for year-round performance using the "Dynamic Daylight Performance Metrics (DDPM)". The DIVA plugin was used to perform the daylight analysis via integration with Radiance and DAYSIM (Reinhart & Wienold, 2011). DIVA (which stands for Design Iterate Validate Adapt) is an environmental analysis plugin for the Rhinoceros 3D Nurbs modeling program (McNeal, 2015). The occupied time for daylighting simulation was from 8AM to 6PM. Simulations were carried out at 300 Lx on the bed plane, where measurement was calculated for three points spaced at a grid of 0.7 m intervals on the bed surface and the rest of analysis points covered the rest of the room.

Three Daylight Availability evaluation levels were used: “daylit”, “partially daylit” and “over lit” areas. The “daylit” areas are those areas that received sufficient daylight at least half of the year-round occupied time. The “partially daylit” areas are those areas that did not receive sufficient daylight at least half of the year-round occupied time. The “over lit” areas are those areas that received an oversupply of daylight, where 10 times the target Illuminance was reached for at least 5% of the year-round occupied time (Reinhart & Wienold, 2011).

The acceptance criterion adopted in this paper assumed that the cases where the “daylit” area reached

<table>
<thead>
<tr>
<th>Table 1 Simulation Parameters</th>
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<tbody>
<tr>
<td>Patient’s Room Parameters</td>
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<tr>
<td>Reflectivity Ratios</td>
</tr>
<tr>
<td>Ceiling: 80% White Paint</td>
</tr>
<tr>
<td>Walls: 50% Medium Off-White Paint</td>
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<tr>
<td>Floor: 20% Wooden Floor</td>
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<tr>
<td>Shading: 50% Medium Off-White Paint</td>
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<tr>
<td>Visual Transmittance</td>
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<tr>
<td>Window: 80% Double Clear</td>
</tr>
<tr>
<td>Modelling parameters</td>
</tr>
<tr>
<td>Area: 11.84 - 14.43 m²</td>
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<tr>
<td>Horizontal Wall Divisions</td>
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<tr>
<td>3 to 4</td>
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<tr>
<td>Vertical Wall Divisions</td>
</tr>
<tr>
<td>1 to 2 per wall segment</td>
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<tr>
<td>Wall Segment</td>
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<tr>
<td>4 segments</td>
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<tr>
<td>Wall Segment transformation limits</td>
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<tr>
<td>0.7 m</td>
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<tr>
<td>Minimum number of solid Divisions</td>
</tr>
<tr>
<td>First row of horizontal divisions (4 to 8)</td>
</tr>
<tr>
<td>Outside shading system</td>
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<td>45 cut-off angle</td>
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≥ 50% of the tested space were considered having “acceptable” performance. Cases having 100% daylit area over the bed coupled with more than 90% daylit area of the Patient room area were considered “successful”, since these ensure sufficient daylighting performance at the patient bed where medical care is performed.

RESULTS AND DISCUSSION

Use of the optimization method proposed in this study succeeded in providing a wide range of design variations. This allowed for showing the effectiveness of using the proposed parametric approach in identifying a large number of unconventional designs that maintain maximum daylighting performance. This is demonstrated in Figure 4.

The optimization process was finished after 262 simulation runs. As shown in Figure 4, simulation results were ordered from the worst performance to the optimized ones that achieved 100% daylit area on both the bed area and the room area, with 0% of partially-daylit and overlit areas. The optimum solutions had an almost similar daylighting performance, even though they were completely different in regards to the façade wall configuration. Samples of the most unique of these configurations are illustrated in Figure 5.

The genetic algorithm adopted in this study enhanced daylighting performance during the optimization process gradually through 29 Generations, by which the objective was set to maximize daylit area percentage and to minimize the over-lit and partially-daylit area percentages. In the last generation, by the end of the optimization process, 42 optimum solutions were defined. These all met the targeted criteria.

CONCLUSION

This paper demonstrates that parametric workflows and optimization can be effectively used to generate unconventional patient room façade designs that provide superior daylighting performance. The approach developed in this study manipulated the external wall façade at efficient inclination angles and changed window distribution for the optimization of daylighting.

A large number of solutions were developed, where 100% daylit area on both the bed area and the room area, with 0% of partially-daylit and overlit areas were achieved. These results were not attainable with the use of traditional methods of simulation by trial and error. Experiments showed the effect using automatic optimization techniques in manipulating wall configuration in order to achieve 100% daylit spaces. The approach proposed in this study produced a wide range of unconventional façade designs. Apart from conventional 2D plane facades, new results were developed where formal design aspects were integrated with the requirements of daylighting performance. Using this approach, a new set of unexpected design solutions that comply with daylighting requirements was generated. Thus, the proposed methodology provided another design perspective that could be used in the early design stages, where decisions leverage both form aspiration and performance limitation.

The proposed approach is currently limited to daylighting aspects. It does not account for other important performance factors such as acoustic, thermal and external view exposure. Addition of these aspects to the optimization process will help narrow down the alternatives to the ones that comprehensively achieve a balanced performance.

ACKNOWLEDGEMENT

This publication is based on research work supported by a research grant from The American University in Cairo.

Figure 4 Optimization results according to Daylight Availability metric
Figure 5 Facade configuration based on the optimum results
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