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Designing Daylight Responsive Facade Shading System Integrated with Curved Origami Structure

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Abstract: Responsive facade can be considered to adopt the strategy of learning from nature to provide a more efficient and effective performance of architecture technologies. However, many of the existing facades neglect the potential for an integrated relationship between the building envelope and the structure itself, which when combined could result in a system that supports itself. The research demonstrates the possibility of integrated functionality and proposes a potential direction of developing interactive facade with regard of environmental issues. To achieve the adaptability of environmental conditions and provide the potential opportunity of integrating structural capacity with the performance; simultaneously, the responsive facade attempts to be a systematic baffle zone which can be efficiently utilized for smoothing the transition of light and temperature. The conceptual proposal is approached by the alternative test of physical models and computational process. This can avoid the gap between conceptual design and realistic construction and generate by the method of design by making.

Key Words: Responsive shading device, Curved origami, Environmental adaptability, Orientated structure performance

1.1 Introduction

It is recognized responsive facade can be considered to adopt the strategy of learning from nature to provide a more efficient and effective performance of architecture technologies. Many of the existing facades neglect the potential for an integrated relationship between the building envelope and the structure itself, which when combined could result in a system that supports itself. Advanced facade should be expected as a comprehensive system with integrated functionality which not only considers the response to the external environment but also the efficiency of bearing capacity. Origami method, as its advantages of flexibility and controllability, has widely used in architecture realm for many years. Particularly, the curved origami has a specialty with regard to structure. Therefore, to review the essential factors of facade design with respect to structural performance, compliance of environmental conditions and aesthetics, a sun shading device has been designed with character of curved folding instrument.

1.2 Making process

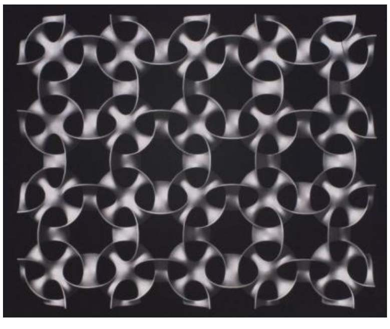

Figure 1. Sculpture: Intercircles (Design by Erwin Hauer 2002)

The configuration is inspired by one of E. Hauer's classic screens known as Intercircles (Fig.1). Due to benefits such as its strong aesthetic appeal in its geometry whilst simultaneously presenting an orientated structure, potentially incorporating it into a facade component is possible. However, it has some limitations such as the sculpture uses concrete for construction; the heavy and stable configuration has little potential to be a facade of buildings. Therefore, the new idea is a modification of the intercircle screen which is improved by integrated it with the origami method.

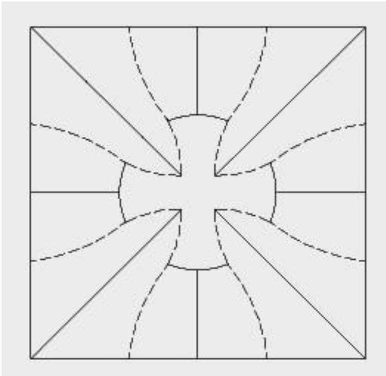

Figure 2. Typical plan of fa çade unit

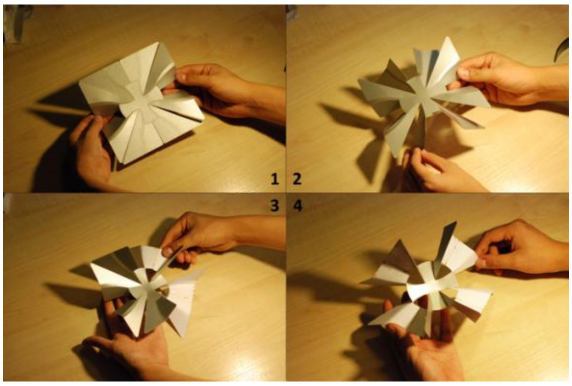

Figure 3. The process of making unit

To start making the basic unit of the surface, the square sheet will be cut following the real lines and then reversely folded following the dashed lines. After that, joining two cut edges is required in order to combine them into a single plane, resulting in the completion of a single unit (fig.2 and fig.3). Thus, the modified surface maintains the benefit of E.Hauer's screen by being defined in units in order for fabrication and assembly to become appropriate.

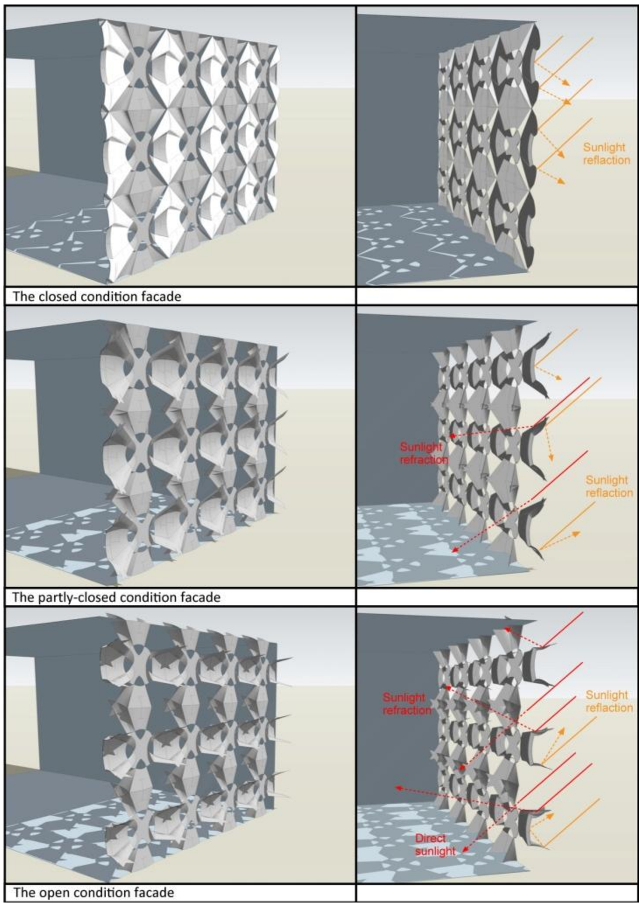

Figure 4. The light effects in three conditions

1.3 Environmental adaptability

1.3.1 Dynamic control of flaps

It is noticeable that there are some triangular shaped flaps turned upwards whilst the remaining flats are turned downwards. They are the natural extension of the geometry with regard to the square shaped paper sheet. Moreover, component made by four basic units performs as a dynamic shading device using these 8 flaps. Hence, the flaps considered as the leaves of the louvre system provide sufficient shading when closed; whilst allowing the external daylight to enter and offering a large amount of ventilation when the triangles are opening.

Additionally, the small holes in the basic unit can support the introduction of daylight into indoor space and meanwhile offer ventilation when the flaps are closing. Benefiting from a curved surface, the triangular flaps produce shading in various directions that could efficiently transform the direct sunlight into soft light into indoor space, especially with a high solar altitudinal angle (fig.4).

The simulation of potential dynamic activities has tested in Rhinoceros with the plug-in grasshopper. The rotation of the outer segment of the flaps can be controlled by manipulating the slider. Hence, with appropriate material (e.g. pine cone smart material), the spider unit repeatedly mapped on the facade can provide dynamic shading in response the various environmental conditions.

1.3.2 Variation of spider unit in order to meet different shading and ventilation requirement

The variations of the spider unit is analysed by computer models in figure 5. With the help of the grasshopper plug-in for Rhinoceros, some parameters of the unit model can be manipulated to achieve the dynamic activity as well as to evaluate the flexibility of the unit in the digital realm. The variation is analysed by operating the inner radius and outer radius. The inner radius indicates the width of the cross shape and the outer radius points out the area of the central circle. Particularly, the bigger inner radius produces a larger cross width; the bigger outer radius produces a larger circle area. From the diagram, it is distinct that the configuration 3 with inner radius 2.9 and outer radius 15.9 has the largest holes, in contrast, the holes in the configuration 7 with inner radius 7.9 and outer radius 8.9 is covered by the cross. It can be predicted that the configuration 3 can be applied where good ventilation is required while configuration 7 is suggested for installation in places that require more shading. Additionally, the variation by outer radius and inter radius is shown in figure 6.

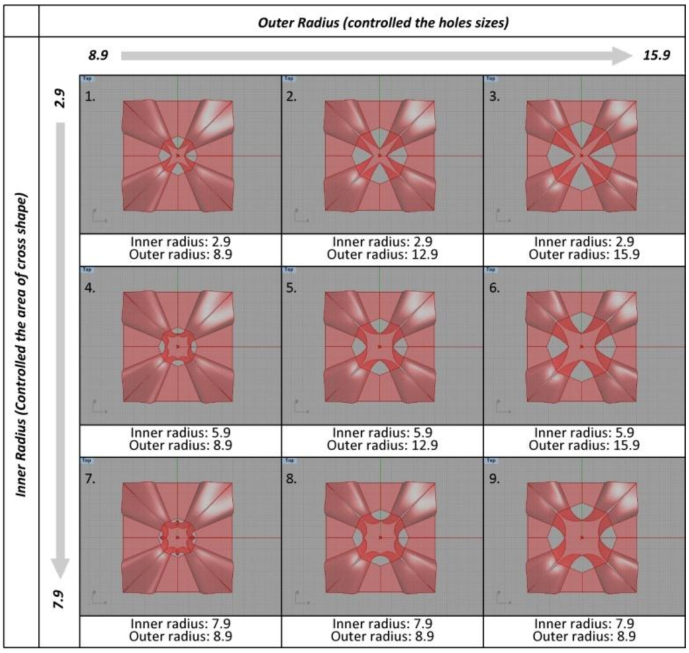

Figure 5. Variation of configuration in Rhinoceros

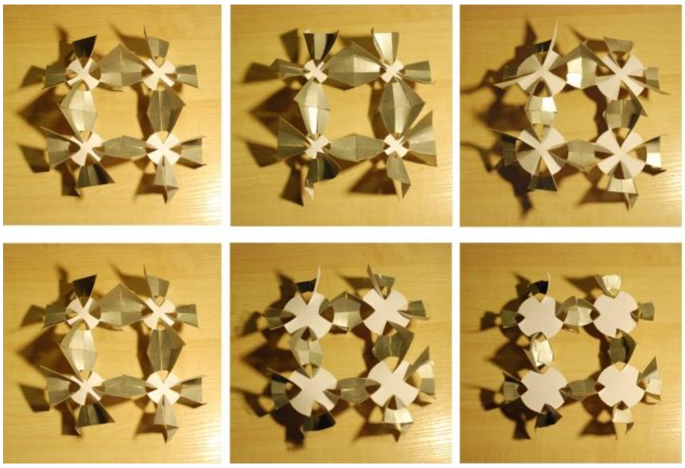

Figure 6. Various configurations in physical models

1.4 Evaluation

As discussed above, the dynamic façade unit is conceptually able to highly adapt the changing climate. The subsequent work focuses on assessing the responsibility to light by the application of Ecotect to reflect the performance of environmental adaptability.

The daylight factor is a parameter that is used to assess the sufficiency of natural light in internal space. This factor is derived from some algebraic equations which are based on the standard CIE overcast Sky at the specific time of September 21st at 12 pm. The regulations of the use of daylight factor are prescribed as shown below (CIBSE Lighting Guide 10 (LG10-1999)): "*under 2% – Not adequately lit – artificial lighting will be required; between 2% and 5% – Adequately lit but artificial lighting may be in use for part of the time; over 5% – Well lit – artificial lighting generally not required except at dawn and dusk; over 10% –glare and solar gain may cause problems.*"

The implementation of evaluating the lighting performance of the dynamic facade unit contains the measurement of three places with different latitudes which are Riyadh, Nice and London. These cities are selected to be analysed because they located in the areas of different latitudes, and as a consequence, the results of this assessment could potentially be applicable in the majority of cases. More specifically, Riyadh located in Saudi Arabia has the latitude of 24.6500 ° N, and it stands for the majority of places in tropical weather where the sun shading system is required in order to balance the light environment indoors i.e. the daylight factor should keep below 10% to avoid the problems caused by over-gained of glare and solar. Nice and London are the typical cities which located in the area of higher latitude. They do not obtain as much sunlight as that in Riyadh or even perhaps are lack of sunlight, thus, the buildings there require shading device for the sake of energy efficiency i.e. the daylight factor should at least achieve 2%.

With regards to the variation of glazing ratio of the dynamic façade (fig.7), it is clear that a larger value of glazing ratio (window ratio) could obtain a higher value of daylight factor, hence the daylight factor test should consider different values of glazing ratio to examine the light conditions not only for low value of glazing ratio as well as over capacity of interior sunlight in high value of glazing ratio. More exactly, three different conditions with regard to glazing ratio are evaluated in this test – closed condition (15%), partly closed condition (40%), and open condition (65%). Figure 8 combined the testing results in three cities in order to exhibit the changes of the value of daylight factor with respects to three different conditions. The X-axis in the figure represents three different conditions where 1 is the closed condition while 3 is open condition. As it can be seen from the figure, the dynamic facade unit designed in this project is considered to show reasonable light performance when using it in Nice and London since the values of daylight factor are in the range of [2.0,10.0].

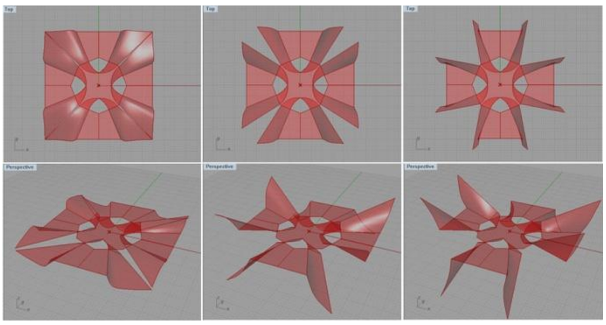

Figure 7. Closed condition, the partly-open condition and open condition from left to right

However, as far as using it in Riyadh is concerned, when the facade is either partly closed or opened, it could cause some problems due to overheating (the values of daylight factor are above 10% under partly closed condition and opened condition).

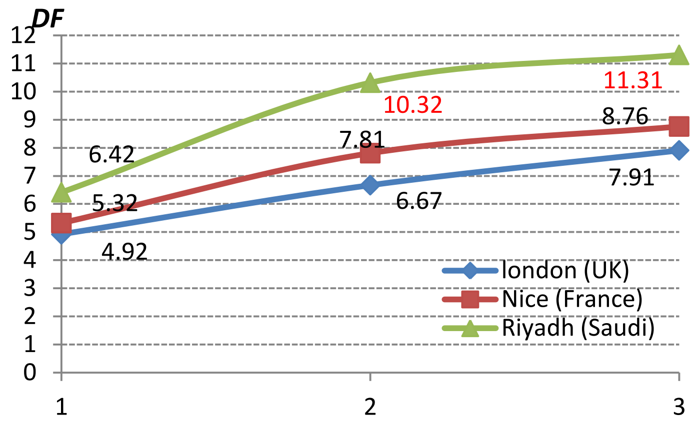

Figure 8. Daylight factor of the dynamic system with the standard spider unit in different cities

Consequently, the unit needs to be modified as mentioned (section 1.2.1), the figure 9 shown that smaller the central holes are changed for better shading function. Hence, the glazing ratio of the modified unit is 7% in the closed condition, 32% in the partly-closed condition and 75% in the open condition.

Figure 10 shows the comparison between the original unit and modified unit and it is clear that with the modification of unit, the dynamic facade achieves the requirement of interior light comfort. Meanwhile, it demonstrates in turn that the variation of configuration of spider unit provides the opportunity to apply this facade in majority places of the world.

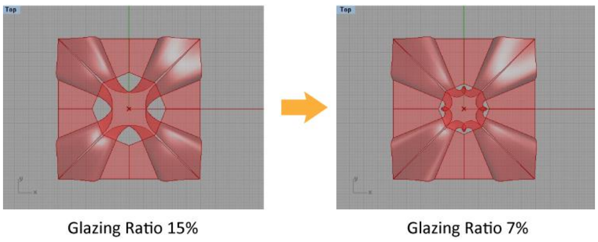

Figure 9. The modified unit (left) and standard unit (right)

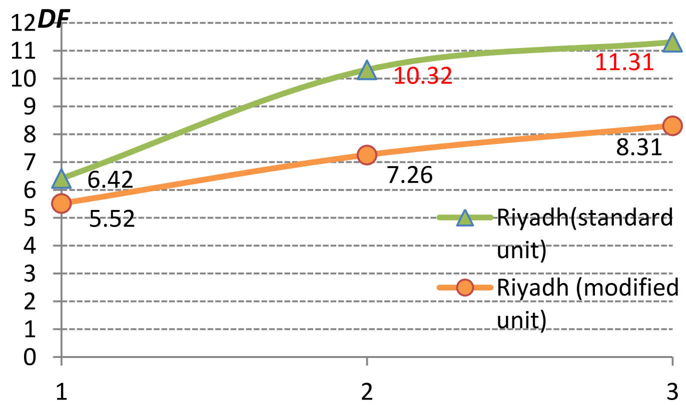

Figure 10. The shading performance of modified unit comparing with that of the standard unit

1.5 Conclusion

This research provides an opportunity to integrate the environmental adaptability with orientated structure and aesthetics in façade design by discovering the methodology of curved origami. To specific, the conceptual design has an excellent standard of responsibility by its adaptable flaps; meanwhile, it could be installed world-widely due to the flexible configuration. Hence, the shading device proposed shows its great lighting response in terms of different environmental conditions (fig.9, fig.10). The future work including the prediction of its mechanical behaviours and the determination of the selection of smart materials which could be an alternative choice of achieving its mobility should be conducted.

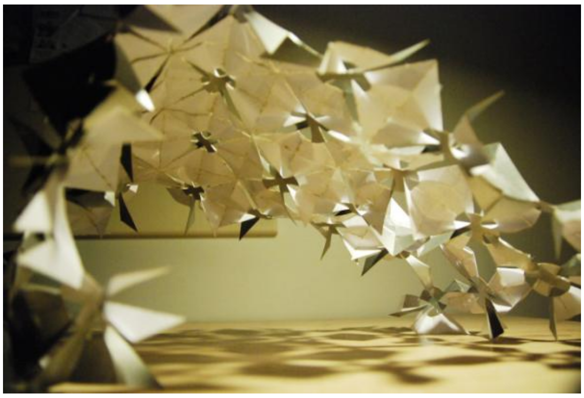

Figure 9. Structure performance shown in physical model

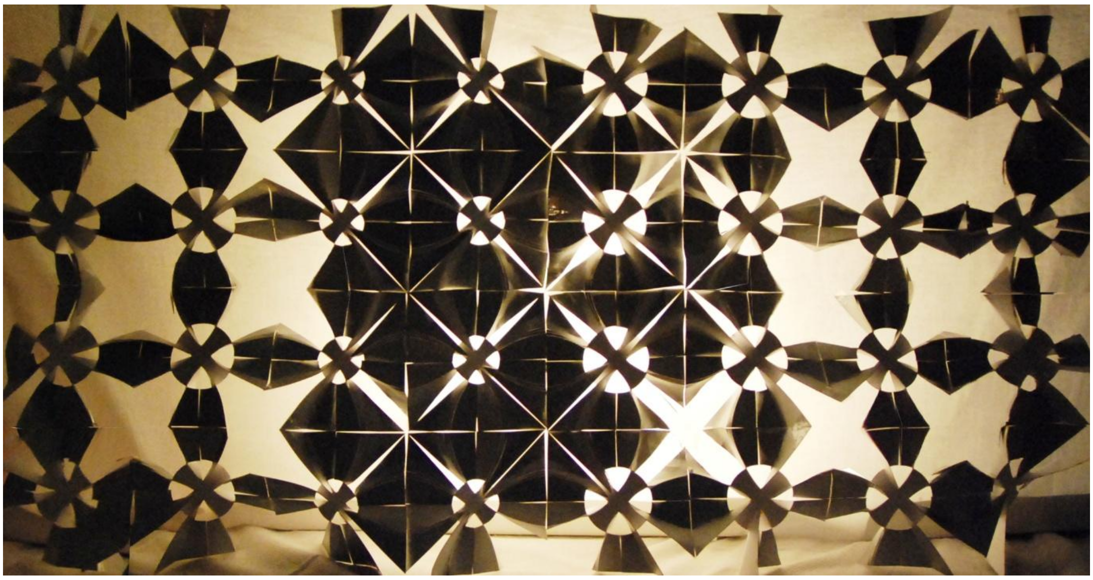

Figure 10. Lighting influence by physical model

Reference

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