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Modified Yoshimura Pattern for Lighting Environment Education*

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Abstract. Yoshimura pattern is one of the most typical paper folding methods in the field of lampshade design. A Yoshimura pattern is a set of skew quadrilaterals, and each is composed from two planar triangles. Lampshades manufactured with Yoshimura pattern have a nonuniform luminance distribution overall, however, the luminance distribution within a skew quadrilateral unit is discontinuous at the border between the two planar triangles in the unit. The author found that similar shapes can be constructed as a modified Yoshimura pattern by the SQED method. Furthermore, he also found derivative shapes which can be covered by skew quadrilaterals. Finally, the author explains how examples of such shapes are useful in lighting environment education.

Key Words: paper folding, skew quadrilateral, lampshade, luminance distribution, lighting environment education, Descriptive Geometry education

MSC 2010: 51N05, 97G80, 00A66

1. Introduction

Traditional Japanese lampstands were manufactured from paper historically. The paper folding method was adopted into some Japanese lampstands and Western lampshades (see [4]). If we put a non-flat texture on the surface of lampshades obtained with the paper folding method, a nonuniform luminance distribution appears according to the basic laws of illuminance. Such nonuniform luminance on the surface of lampshades contributes to an easier recognition of its shape and to a more attractive appearance.

Yoshimura pattern [7] is one of the most typical paper folding methods in the field of lampshade design. This pattern is known as structure of a crashed cylinder [7] or structure of a building roof [3], and has been well utilized in commercial lampshade products and beverage cans. Besides, cylindrical Yoshimura pattern and dome type Yoshimura pattern [2] have

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been proposed as well. Miura called these shapes "pseudo-cylindrical concave polyhedral" and expored several features of the shell structure [1]. A Yoshimura pattern structure is a set of skew quadrilaterals, and each is a compound of two planar triangles. Consequently, lampshades manufactured with Yoshimura pattern have a nonuniform luminance distribution overall. However, the luminance distribution within a skew quadrilateral unit is discontinuous at the border between the two planar triangles in the unit. The author found that similar shapes can be constructed as a modified Yoshimura pattern, and he also found derivative shapes which can be covered by skew quadrilaterals.

The paper begins with an explanation of modified Yoshimura patterns and the related paper folding method. Then, shapes made by this SQEF method are presented. Finally, it is shown how shapes made by the proposed method can be used in the field of lighting environment education.

2. Principle of modified Yoshimura pattern

The proposed paper folding method is based on the Yoshimura pattern [7]. As shown in Figure 1, the development of a cylindrical Yoshimura pattern has two sets of oblique parallel lines at even intervals for mountain folds and one set of horizontal parallel lines at even intervals for valley folds.

The cylindrical shape shown in Figure 1 appears after folding the development alongthe lines drawn in the development and bending the development by glueing together the bilateral sides without gap and overlap. In case of a shape made from cylindrical Yoshimura pattern, each diamond in the development changes its shape to a skew quadrilateral unit, which is composed from two planar triangles. Consequently, the luminance distribution in the area of each single unit is discontinuous at the border between the two triangles.

As shown in Figure 2, a similar shape appears after folding the development shown in Figure 1, but only with the lines for mountain folds, and bending it. The author named this folding method *"skew quadrilateral elastic folding"* (hereafter, SQEF in short).

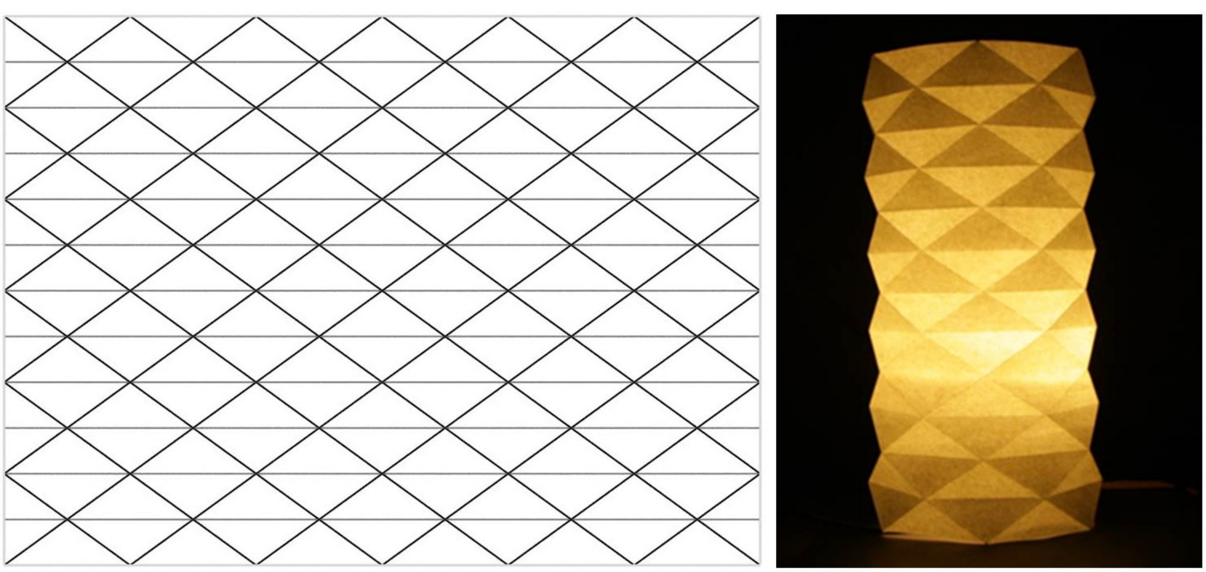

Figure 1: Development of the Yoshimura pattern (left, black lines for mountain folds and grey lines for valley folds) and the cylindrical shape made from the development (right)

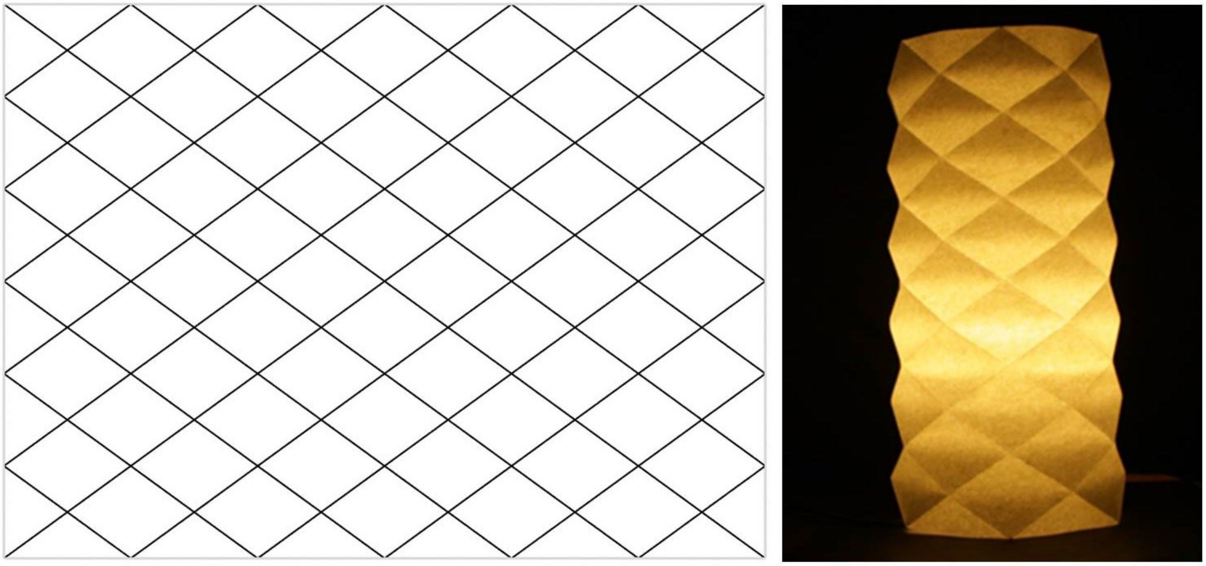

Figure 2: Development of the modified Yoshimura pattern (left, black lines for mountain folds) and the cylindrical shape made from the development (right)

Figure 3 shows photos of the brightness distribution on the surfaces of the shapes made either by the original Yoshimura pattern or by the SQEF method. With regard to the brightness distribution in a diamond unit, at the shape made by the SQEF method the brightness values of the upper and the lower side are quite different. But at almost all quadrilateral units there exists a buffer zone between with a continuous transition from the upper side values to the lower side values.

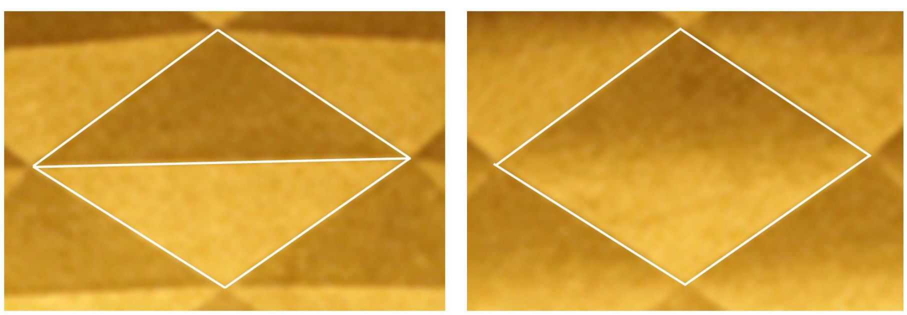

Figure 3: Brightness distributions on the surfaces of Yoshimura pattern (left) and that of the shape made by SQEF method (right)

In case of shapes made by the SQEF method, each skew quadrilateral encloses a continuously curved surface, and the brightness distribution is continuous within the area of each unit, as shown in Figure 3. From the viewpoint of shapes, the difference between the two shapes can be neglected. However, from the viewpoint of brightness distribution, the difference is significant. Though the luminance on a diffuse transmitting surface, measured from outside, is determined by the direct illuminance and the indirect illuminance of the corresponding inner point, the contribution of direct illuminance is higher when considering the relative variation of the luminance distribution.

As shown in Figure 4, the direct illuminance, given by a point light source, can be calculated using the basic illuminance laws, the *Inverse Square Law of Illuminance* and the *Cosine Law*

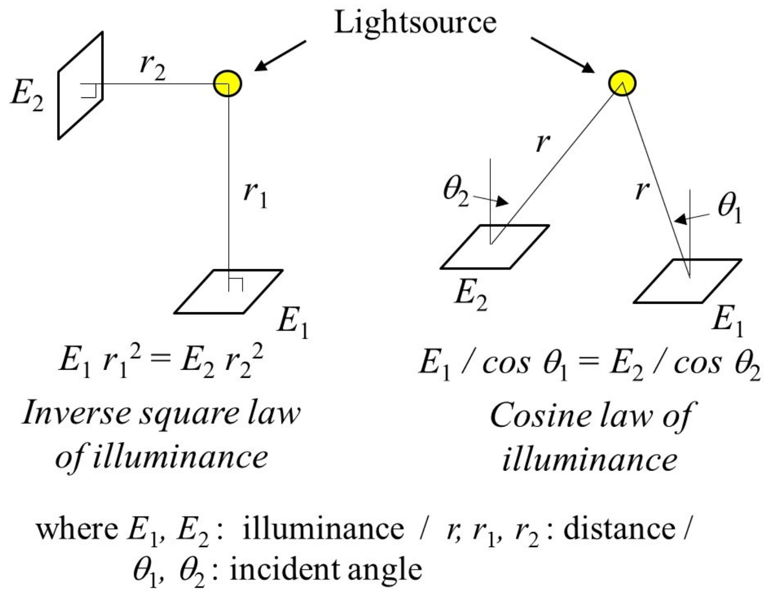

Figure 4: Basic laws of illuminance distribution

of Illuminance. The brightness distribution shown in Figure 2 is mainly based on these basic laws of illuminance. In this experiment, a LED lamp, which can be considered as point light source, was used as light source of the shape. If a larger light source is used the change of the luminance distribution becomes unclear, because the inner brightness distribution of the shape does not follow the basic illuminance laws for a point light source.

3. Derivative shapes made by the SQEF method

As explained in Section 1, if in the development the unit diamonds with valley folds are placed radially a dome shape can be obtained. Dome type Yoshimura pattern is a variation of cylindrical Yoshimura pattern. Analogously, a dome shape can also be obtained by the

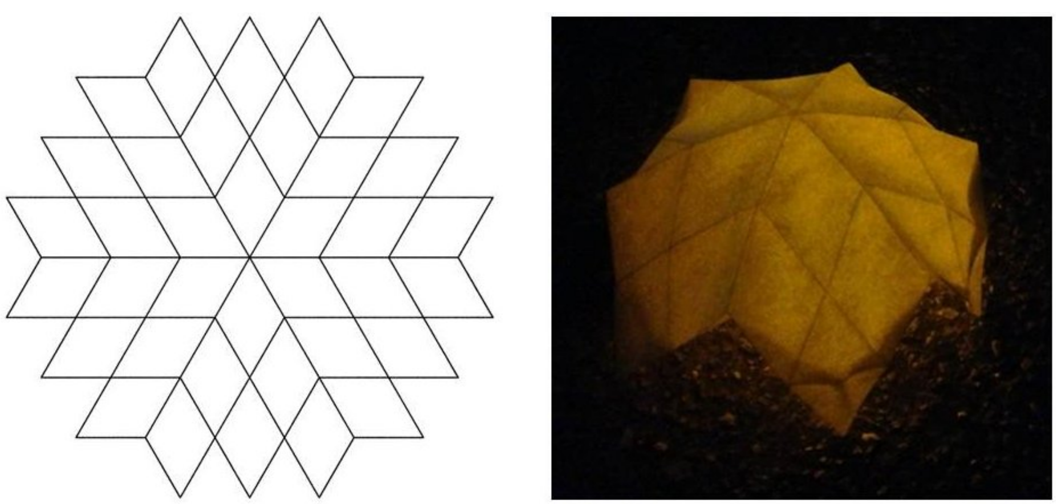

Figure 5: An example of the dome type SQEF with the development (left) and the corresponding shape (right)

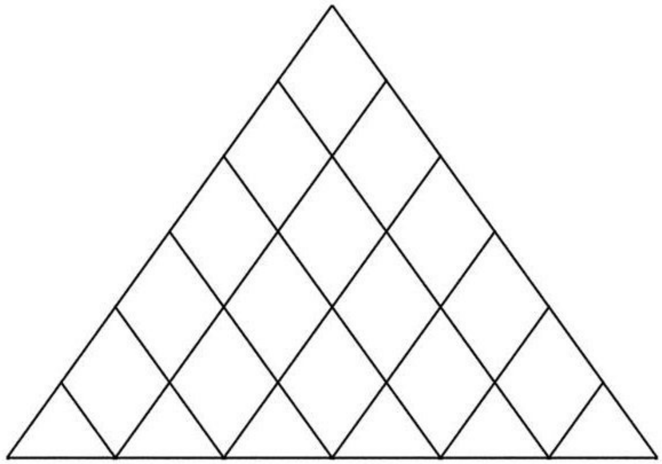

Figure 6: Example of a conical SQEF: development (left) and corresponding shape (right) (after bending, the top and the bottom of the conical shape are cut off horizontally)

SQEF method. As shown in Figure 5, the development of a dome type SQEF is made by diamonds without valley folds, placed radially from the center. After folding and bending of the development, the dome shape can be obtained. Like before at the cylindrical SQEF method, each quadrilateral unit encloses a curved surface.

Figure 6 shows, as an example, the development of the conical SQEF method and the shape made from the development. As shown in the figure, the conical SQEF method is also a variation of the SQEF method. In this case, the paper should be bent to produce the conical shape after folding.

Figure 7 is an example for the non-parallel SQEF method. Corresponding fold lines, which meet on the attached edges, are designed to be jointed smoothly. As shown in the figure, the non-parallel SQEF method is one of the variations of the SQEF method, as well.

Figure 8 shows an example of the left-right asymmetry SQEF method, a development and the corresponding shape. As demonstrated in the figure, the two sets of lines, which form the quadrilaterals, are not limited to be in left-right symmetry.

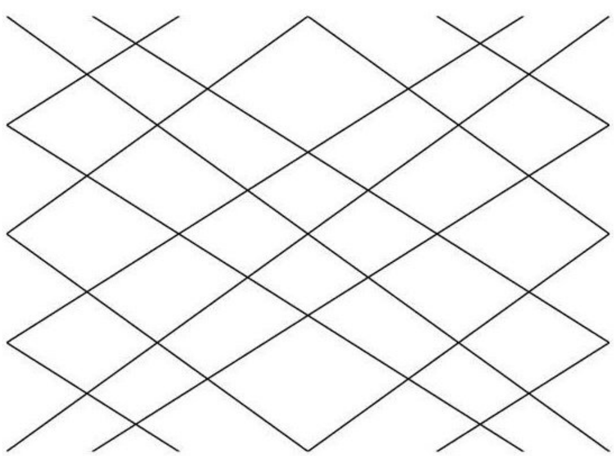

Figure 7: An example of non-parallel SQEF with development (left) and the shape made from the development (right)

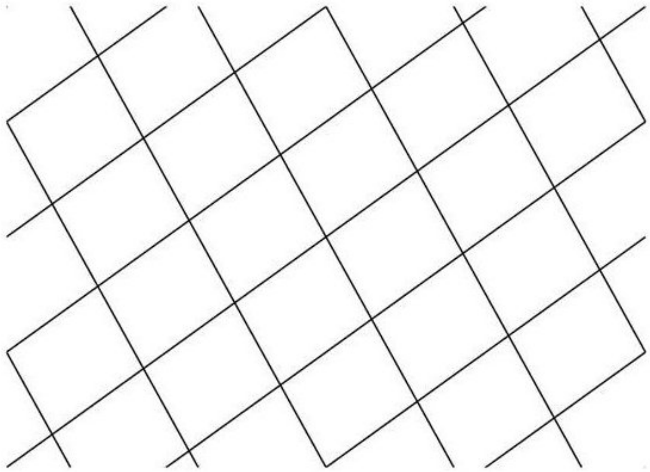

Figure 8: An example of left-right asymmetric SQEF: development (left) and the corresponding shape (right)

4. Application of SQEF shapes in the field of lighting environment

Historically, the knowledge and technique about lighting environment is one of the essential factors in the Descriptive Geometry education. Students sometimes have to understand the brightness distribution by construction or intuitive estimation and to express it on their drawings. Though the dominant principles for brightness distribution are the two basic laws of illuminance distribution, as described in Section 2, it is difficult for students to estimate the approximate brightness distribution intuitively without any exercises.

Lampshade is an appropriate subject to learn the brightness distribution generated by a relationship between shape and light. The author introduced the lampshade design assignment into the Graphic Science Education course [5], and he introduced also the paper folding lampshade design assignment into the course [6]. As the manufacturing process of the shape

Figure 9: Example of a lampshade with candle light manufactured by a high school student who participated in a special lecture at the Kobe university

made by the SQEF method is simple enough, SQEF has a large potential in the field of lighting environment education. Table 1 shows a list of classes and workshops where shapes made by the SQEF method have successfully been used. In each class or workshop, the participants were requested to construct a paper folding lampshade as shown in Figure 9. In some classes the participants had to make a perspective (Figure 10) or an isometric drawing (Figure 11) of the shape in order to cultivate their ability to estimate and express the brightness distribution.

The behavior of transmission depends on the material of the shape. Therefore, lampshades made from stainless mesh and plastic sheet were constructed as well, in order to compare the different brightness distribution on the shades (see Figure 12).

Table 1: A list of classes and workshops where SQEF shapes have successfully been used

Date	*Place*	*Style and Target*	*Drawing*
15th Jun. 2014	Design and Creative Center Kobe	Craft Workshop for Students and Children	
5th Nov. 2014	Riga Technical University	Open Lecture for Students	
7th Nov. 2014	Vilnius Gediminas Technical University	Open Lecture for Students	
12th Dec. 2014	Kobe University	Special Lecture for High School Students	
Fall Sem., Academic Year 2014	Kobe University	'Descriptive Geometry Excercise' for Students of Departments of Architecture and of Civil Engineering	Perspective
Spring Sem., Academ. Year 2015	Setsunan University	'Exercise of Space Expression II' for Students of Department of Living and Environmental Design	
11th Aug. 2015	Kobe University	Open Lecture for High School Students	
30th Aug. 2015	Nishisuma Primary School	Craft Workshop for Students and Children	
17th Sep. 2015	Aarhus University	Open Lecture for Students	
20th Nov. 2015	Nagata High School	Lecture for High School Students	
Fall Sem., Academic Year 2015	Kobe University	Descriptive Geometry Excercise for Students of Departments of Architecture and of Civil Engineering	Perspective
Fall Sem., Academic Year 2015	Setsunan University	'Exercise of Space Expression B' for Students of Department of Living and Environmental Design	
21th Dec. 2015	Vilnius Gediminas Technical University	Internet Lecture Exchange for Students	
Spring Sem., Academ. Year 2016	Otemae University	'Perspective Drawing Excercise' for Students of Department of Architecture / Interior	Isometric
24th Oct. 2016	Vilnius Gediminas Technical University	Open Lecture for Students of Faculty of Architecture	
27th Oct. 2016	Vilnius Gediminas Technical University	Open Lecture for Students	

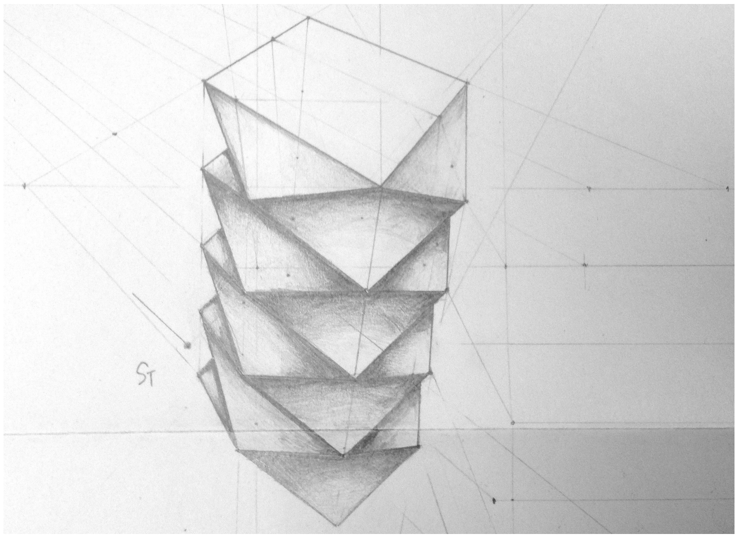

Figure 10: Example of a submitted perspective drawing of a shape made by the SQEF method

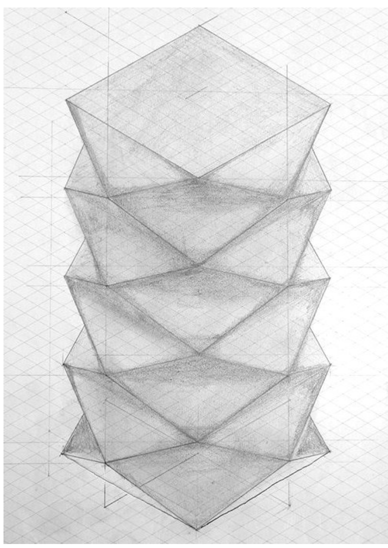

Figure 11: An isometric drawing of the shape made by the SQEF method

Figure 12: Examples of the shape made from stainless mesh (left) and plastic sheet (right)

5. Conclusions

This paper started with the principle of the proposed paper folding method. Then, derivative shapes made by the SQEF method were presented. Finally, examples of application of SQEF shapes in the field of lighting environment education were presented.

It seems that there are many possibilities for applications of the SQEF method. Especially, the author would like to study the following topics intensively:

- Design of more complicated shapes made by the SQEF method.
- Analysis of the exact shape made by the SQEF method using both mathematical methods and a 3D scanner.
- Analysis of the psychological impression given by the surface of a Yoshimura pattern and the shapes made by the SQEF method.

The author would like to continue his research on the SQEF method for developing further applications.

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