Veridian E-Journal, Silpakorn University
ISSN 1906 – 3431

The Study of solar energy for Photovoltaic Sculpture*

การศึกษาพลังงานแสงอาทิตย์เพื่อสร้างประติมากรรมที่ใช้เซลล์แสงอาทิตย์

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Abstract

Renewable energy means the clean energy such as solar energy, wind power, hydropower, etc. These sources of energy will be the world's major resource of energy in the near future. Although the efficiency of the renewable energy production is still low comparing to its cost, but the development is continuously on the way. Currently, the usage of solar energy in Thailand is still limited mostly to the household or industrial usage. In terms of art, solar energy application for aesthetics propose is rare. However, the problem of using the solar panel in any design would be limited technically to the fact that the solar panel must face the sun directly for the full light exposure and maximum efficiency. On the contrary, the artistic beauty might not require the maximum efficiency but rather focus on the aesthetic quality.

This article aims to present the experiment result and confirm that the planar which could face the sun in multi directions would affect the design, which might not always have to face the sun directly. The multi-direction planar would lead to more variety in artistic design and the interesting forms of aesthetic qualities. Apart from the artistic benefits, this study could also lead to the various product designs to increase utility and respond to the consumers' needs. In this study, the researcher selected the Monocrystalline solar cell (mono-Si) to experiment in electricity production, together with wood and wire for the sculpture model. The study process started from 1. Site Assessment: Specific location by Latitude will be achieved I. Altitude II. Seasons III. Sunlight direction IV. 2. Photovoltaic Layout Design 3. Design

* The article is a part of the thesis topic "Geometric Design for Kinetic Art Creation with Renewable Energy : Photovoltaic."

บทความนี้เป็นส่วนหนึ่งของหัวข้อวิทยานิพนธ์เรื่อง "การออกแบบรูปทรงเรขาคณิตสำหรับการสร้างสรรค์งานศิลปะจลศิลป์ด้วยพลังงานทดแทน: ไฟฟ้าโซลาร์เซลล์ "

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of Model Sculpture 4. Observation 5. Solar Correction Data for Electric Power 6. Experiment of energy to use in Art. The experiment results confirmed that it was possible to create a sculpture which could generate electricity. The electricity generating instruments could be built and incorporated as a part of the sculpture without requiring any dismantlement. Therefore, the artistic beauty could be combined with the scientific usage appropriately.

Keywords: 1. Solar incident 2. Solar energy 3. Sculpture 4. Photovoltaic 5. Solar cell 6. Light Art

บทคัดย่อ

พลังงานหมุนเวียนเป็นพลังงานสะอาด เช่น พลังงานแสงอาทิตย์ พลังงานลม พลังงานน้ำ เป็นต้น ในอนาคตอันใกล้พลังงานเหล่านี้จะกลายมาเป็นแหล่งพลังงานหลักของโลก แม้ว่าในปัจจุบันยังผลิตพลังงานไฟได้ค่อนข้างต่ำเมื่อเทียบกับต้นทุน แต่ก็มีการพัฒนาค้นคว้าอยู่อย่างต่อเนื่อง ในปัจจุบัน การใช้พลังงานแสงอาทิตย์ในประเทศไทย ยังคงไม่ค่อยแพร่หลายนัก อีกทั้งส่วนใหญ่ ยังมีการใช้เซลล์แสงอาทิตย์เพื่อรับพลังงานแสงอาทิตย์ในลักษณะของการใช้เพื่อเป็นประโยชน์กับการดำรงชีวิต เช่น นำมาใช้กับอาคารบ้านเรือน ใช้กับโรงงานอุตสาหกรรม แต่สำหรับในแง่ของศิลปะนั้น พลังงานแสงอาทิตย์ที่นำมาผลิตไฟเพื่อความสวยงามยังไม่ค่อยได้พบนัก แต่ปัญหาของการนำแผงเซลล์แสงอาทิตย์มาใช้กับงานออกแบบนั้น ก็มีข้อจำกัดตรงที่ต้องหันหน้าปะทะกับดวงอาทิตย์เพื่อรับแสงโดยตรง ซึ่งจะทำให้ได้ประสิทธิภาพการใช้งานสูงสุด แตในทางกลับกัน ถ้าต้องการความงามด้านงานศิลปะ กลับไม่ต้องการประสิทธิภาพสูงสุด แต่ต้องการความสวยงามเป็นหลัก

การวิจัยครั้งนี้มีวัตถุประสงค์เพื่อที่จะแสดงให้เห็นถึงผลจากการทดลองว่า การที่ระนาบพื้นผิวที่หันหน้าเข้าปะทะแสงอาทิตย์ได้หลายทิศทาง อันจะมีผลกับชิ้นงานที่จะออกแบบซึ่งจะไม่ต้องหันหน้าเข้าหาแสงอาทิตย์เพื่อปะทะโดยตรงเสมอไป โดยหน้าระนาบที่หันไปยังทิศทางต่างๆ กันดังนี้ จะทำให้การออกแบบทางศิลปะมีความหลากหลายรูปแบบมากขึ้น ทำให้เกิดความน่าสนใจของรูปลักษณ์ที่มีคุณค่าความงาม ทางสุนทรียศาสตร์ หรือนอกเหนือไปจากงานศิลปะ การศึกษานี้จะนำไปซึ่งการออกแบบผลิตภัณฑ์ต่างๆ ให้เกิดประโยชน์ใช้สอยมากยิ่งขึ้น เพื่อตอบสนองความต้องการของผู้บริโภค

ในการศึกษาครั้งนี้ได้มีการเลือกแผ่นโซลาเซลชนิด โมโนคริสตัลไลน์ที่ทำมาจาก ผลึกซิลิคอนเชิงเดี่ยวมาใช้ในการทดลองเพื่อผลิตพลังงานไฟฟ้า, ไม้และลวดสำหรับการสร้างโมเดลประติมากรรม ขั้นตอนในการศึกษาได้แก่: 1. สถานที่ติดตั้ง : กำหนดจุดพิกัดโดยการระบุเส้นรุ้งเส้นแวง I. ระดับความสูง II. ฤดูกาล III. ทิศทางของแสงอาทิตย์ IV. 2. การออกแบบแผงเซลล์พลังงานแสงอาทิตย์ 3. การออกแบบตัวอย่างงานประติมากรรม 4. การสังเกตการณ์ 5. ค่าตัวเลขของพลังงานที่ได้รับเพื่อนำไปใช้กับอุปกรณ์ไฟฟ้า 6. การนำเอาพลังงานที่ได้ไปทดลองเพื่อสร้างผลงานทางศิลปะ ในส่วนของผลของการทดลองที่ได้ การสร้างประติมากรรมร่วมกับการสร้างพลังงานไฟฟ้า สามารถสร้างและนำอุปกรณ์การผลิตกระแสไฟฟ้ามาร่วมเป็นส่วนหนึ่งของประติมา กรรมได้ โดยไม่ต้องแยกออกเป็นชิ้นส่วนจากกัน เป็นการนำเอาความงดงามทางด้านศิลปะผสมผสานเข้ากับประโยชน์ใช้สอยทางวิทยาศาสตร์ได้อย่างเหมาะสมลงตัว

คำสำคัญ : 1. การกระทบของแสงอาทิตย์ 2. พลังงานแสงอาทิตย์ 3. ประติมากรรม 4. ไฟฟ้าเซลล์แสงอาทิตย์ 5. เซลล์แสงอาทิตย์ 6. ศิลปะเกี่ยวกับแสง

Introduction

Sunlight plays an important role in the natural way of life, as human and animals must feed on the plant which require sunlight to grow. Moreover, the sunlight could also generate energy. And when human could find the way to utilize the solar energy through the research and development, it could be the major source of energy which could respond to the basic need of the human life efficiently. Since then, the solar energy became a crucial source of clean energy for human life sustenance due to its renewability, as Huang and Wu said that "Renewable energy is a sustainable and clean source of energy derived from nature" (Huang YH, Wu JH., 2007, pp. 345)

The sunlight ray is emitted in the form of wave. The solar cell, or photovoltaic (PV) cells, was thus invented to transform the wave energy into electricity. Pearsall and Hill wrote that "PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the PV effect". Solar cell was first discovered by the scientists at Bell Telephone, who found that silicon could generate electricity when exposed to sun. Due to its direct conversion of sunlight into electricity which does not require any moving part nor generate any emission, the solar cells became widely used and could be found from in the small consumer products such as watches or calculators to the space satellites and large power stations feeding electricity into the grid. (Pearsall NM, Hill R, 2001, pp.1) Chenming Hu also defined photovoltaic effect as the phenomenon of producing voltages and currents from the solar cells, which are "the devices in which sunlight releases electric charges so they can move freely in a semiconductor and ultimately flow through an electric load, such as a light bulb or a motor". (Chenming Hu,1983, pp. 6)

Generally speaking, sculpture means the work of art which could be created from wood, stone, metal, or plastic, etc., in both two or three dimensional form. As a form of visual art, sculpture express the formal aesthetic and the implicated meaning. Like all visual art works, which usually involve light in some degree, the sculpture must also be exposed to light in order to express its full aesthetic potential, especially the outdoor sculpture. There is also another emerging form of visual arts called "light art", as mentioned by Russell P. Leslie (2004) that "there is, however, a growing interest in light art, or the works of art in which the light is a primary medium." He continued that although the boundary between light art and other visual

art maybe blurry, but the development in technologies and arts allowed more pieces which seems to be the light art more than any other type of visual arts to be created. And light art could now be found in both permanent and temporary venues. (Russell P. Leslie, 2004,pp. 28).

Figure 1. Lightpaintings, Artist : Stephen Knapp, accessed 27 November 2018, <http://www.lightpaintings.com/>

As mentioned above, there is the possibility that the art sculpture could be combined with Photovoltaic cell, and create both beauty and the energy support for further usage. This could blur the line between art and science together, and could express the stylishness of the renewable energy as an art object. The further development for daily life application would confirm that the sculpture could offer note only beauty but also the energy which would be beneficial for everyday usage.

Therefore, the purpose of the research was to develop the design guideline for art sculpture that could generate renewable energy with photovoltaic cells, which would be beneficial in the development of kinetic arts, sculpture, and light art. The research methodology is practice-based and include the process of creating sculpture using local materials. The final output would be the design guideline to create sculpture with the major concern about the sunlight. The result of this study could be a guideline or inspiration for any designer or sculptor to enhance their imagination, to create beautiful works, to fulfil a design project, or to incorporate the energy value into the work of art.

Objectives

I. To study the Kinetic Arts Design with Renewable energy into a sculpture art form.

II. To research and examine the competency of photovoltaic cell giving electricity power that give enough energy for moving sculpture art form itself.

III. To present the aesthetic of new designed which both beautiful and capability that fulfill needs pass through Kinetic art.

Methodology

This research involved the combination of two subjects, which are the photovoltaic cell application and sculpture design. The researcher thus began with the literature review and the consideration of energy factor as well as the sketches of sculptural form, as the design of sculpture would dictate the form of work including the required electrical instrument, such as the size, amount, or voltage. Likewise, the calculation of the electrical circuit, the wiring, and the position to install the electric instruments on the sculpture would also affect the sculptural form. After the form and required electric instrument were designated, the researcher then combined them together and exposed the sculpture to the sunlight, in order to observe the electricity production efficiency. The generated wattage would be measured into the digits, which would be calculated to see if it would be enough to run the electric instrument on the sculpture. Afterwards, the researcher would provide the creative works as the evidence of applying the experiment results for the artistic merit and conclude the result of the study.

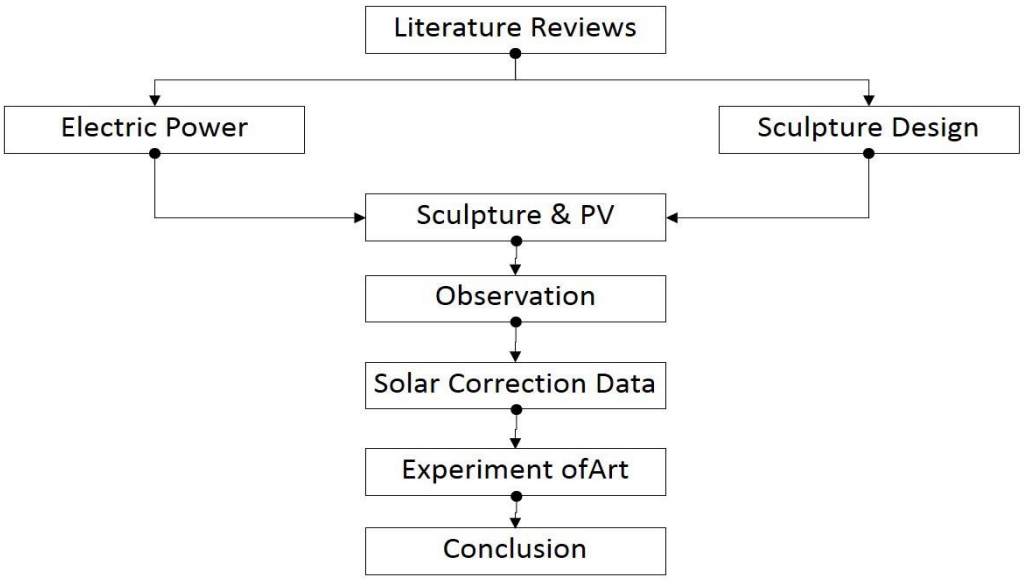

Figure 2. Research methodology.

Experimentation

The experiment procedure, which include 6 steps, can be summarized as following.

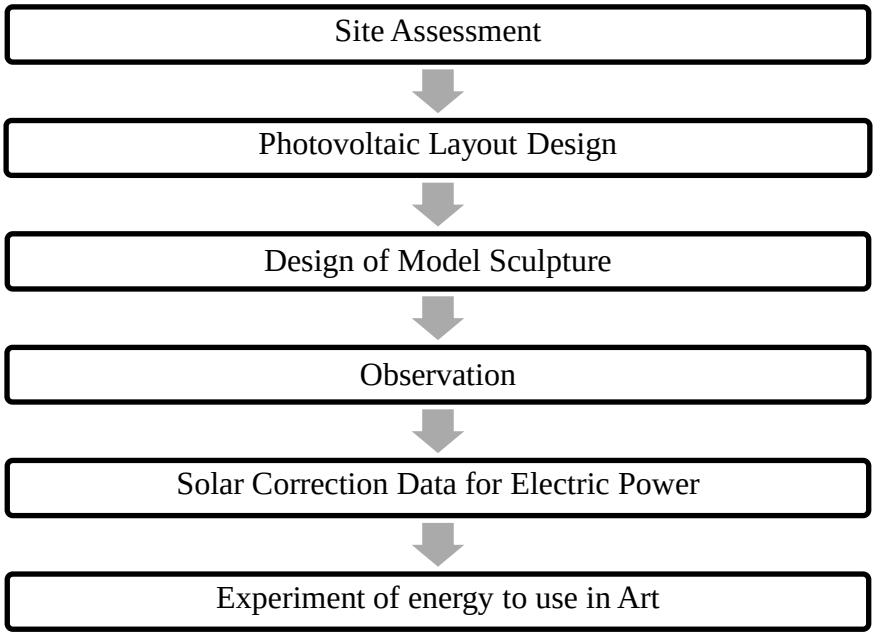

Figure 3. Overall procedure to Development of model appearance in the study site.

Site Assesment

Previously, the researcher wrote about the experiment to find the angle of incidence on the model planar surface in the article “The Study of solar incident on Planar Surface for Kinetic Art”, published in the Reconceptualizing Art Research journal. Afterwards, the researcher created the situation model of the incident light in the 3D program, by designating the angle related to the sun and the earth, which would directly impact the sunlight action towards the solar cell and the shadow from the model on the floor. There was also the mathematic calculation in order to find the different angles between the sun and the earth, in order to recheck the experiment by observation and mathematical calculation. The assessment of electricity generated from the model combined with solar cell was done on Thursday, February 22nd, 2018 (summer) on the rooftop of a residential building beside Bangkok Noi canal, Thailand, at latitude 13° 46' 44.3136" N; 100° 28' 9.012" E. The building faced the north east, with the angle of 33 degrees from the north. The environment was clear, without any obstruction of sunlight, and thus very suitable for the experiment involving sunlight.

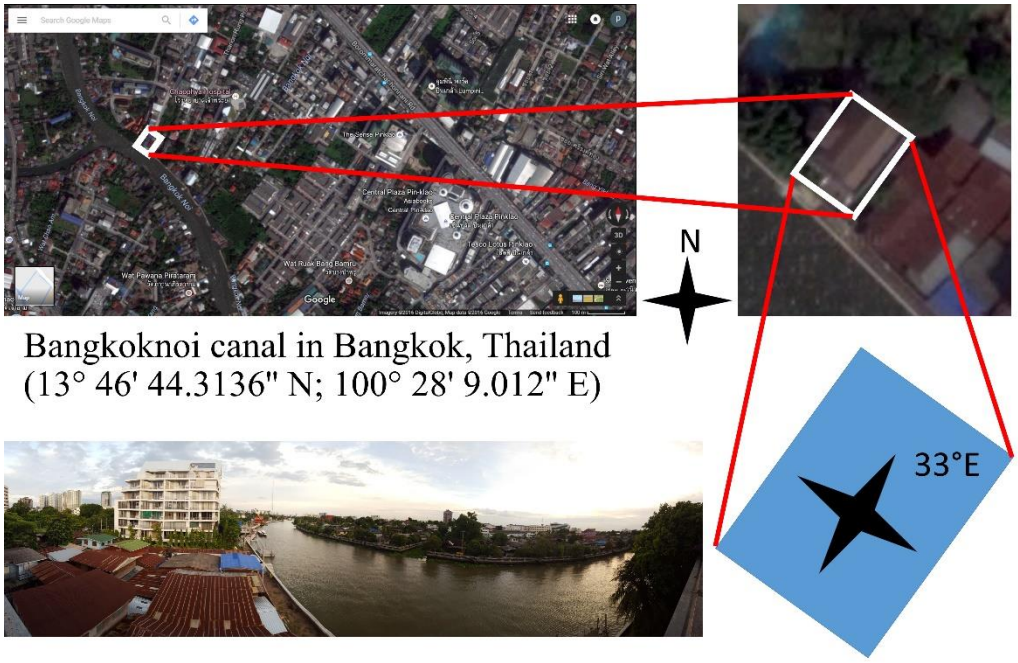

Figure 4. Shows observation site.

Photovoltaic Layout Design

In order to generate enough electricity for the components which would be incorporated, it was necessary to know how much energy should the component need in order to work. Afterwards, the solar cell layout must be designed, with the major concerns of the current and voltage. Firstly, the photovoltaic cell must be select with the consideration of its current and voltage capacity. Then the amount of photovoltaic cell needed in order to generate enough electricity would be calculated.

I. The instrument used in this experiment

a. Motor – a small type motor of 6V 150 mAh

b. Solar cell (Monocrystalline) - 2V 45mAh size 30x30 mm Micro Mini Power Small Solar Cell for DIY light toy.

II. The design of electrical circuit

In order to generate enough power, it was necessary to consider the current and voltage. If any of them is not enough, the component would not work, or might work inefficiently.

Generally, any electrical circuit would be different in terms of flexibility and the characteristic of current and voltage, depending on the circuit connection and the resistor or the electric instrument connection. There are three types of circuit connection as following.

a. Series Circuit

Series circuit is the serial connection of components from one end of a component to the other component. The end of the last component would be connected to the cell. The sum of voltages across the circuit will be higher than the voltage in the parallel circuit

b. Parallel Circuit

When more than two components are connected together in a separate loop, by connecting the same end of each component together, and connect the end of the connected wire to the cell. The sum of the currents would be higher than the series circuit.

c. Compound Circuit

Compound circuit is the use of both series and parallel circuits together, which is mostly found within electronic usage but also possible for other type of applications depending on the appropriate usage. There is no fixed rule for the compound circuit.

All of Solar cell would be added with parallel and series wiring combination. In the series circuit, the total voltage is equal to the sum of the voltage of each cell, and the current is the same as any single cell. In the parallel circuit, the total current is equal to the sum of the current of each cell, while the voltage remain the same for each individual cell. Power is voltage times current.

In this experiment, the researcher incorporated the small motor, which required 6 V 150 mAh, with the photovoltaic cell and could generate electricity of 2V 45 mAh. In order to reach the required power, the compound circuit was used so that the current and voltage would reach enough level for the motor. However, as the photovoltaic cell did not all face the sunlight directly, the total power would be decreased. Thus, the researcher added more solar cell to compensate for the loss of electrical power when the planar was tilted. The solar cell panels were increased from 6 rows and 4 columns, which would generate 6V 360 mAh, to 6 rows and 5 columns, which would generate 6V 450 mAh. The photovoltaic cell layout followed the diagram in figure 5.

Veridian E-Journal, Silpakorn University
ISSN 1906 – 3431

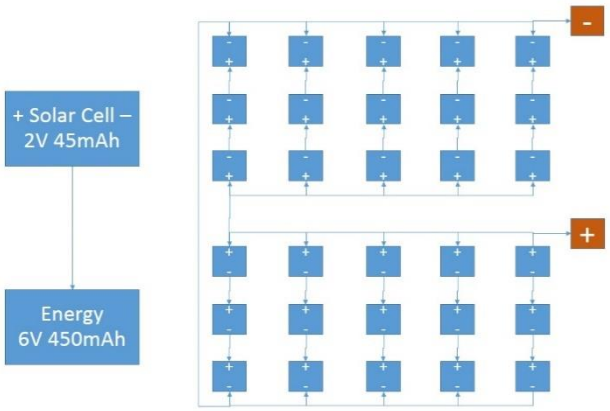

Figure 5. 30 pieces of Solar cell DIY light toy would be added with parallel and series wiring combination in 6 rows and 5 columns.

Design of Model Sculpture (Planar surface)

For the purpose of the study, it was hypothesized that planar surface of model constitutes a tilt array for the highest value of energy generation. The solar cell attached on the surface was designed with the following parameters: number of planar per model (if there are separated), long period receiving energy and array spacing.

I. Model Surfaces

Dmitri Kozlov (2013) wrote about the structure of planar surface that it consisted of three major elements; the planar facets (F), linear edges (E), and point vertexes (V). When these three elements are combined, the sub-units of surface would become the larger surface with the new different forms. The folding of the two major elements; the planar facets (F) and linear edges (E) would especially become the hinged flat faces and the triangular surface as shown in figure 5a. Another type of structure, or the kinematical nets with non-triangle meshes is also possible as shown in figure 6b.

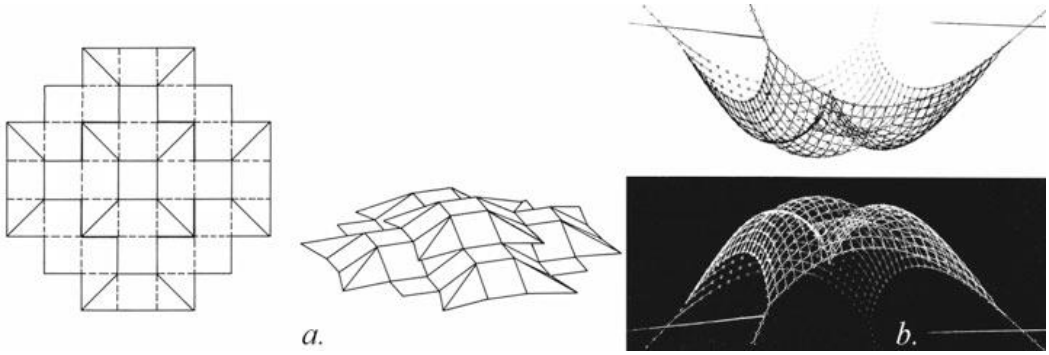

Figure 6. x.Transformable surface models: a) folding structure (Vranka 1990: 9);
b) kinematical net (Otto, Burkhardt and Hennicke 1974: 130)

Furthermore, Shirley Jo Probert (2014) studied about the combination of the geometric forms and found that the emergence of space would start at the origin of the set of all points. Then the sets of points would be divided, and connected together by the line, which would led to the paths (both straight and curved). The crossing of the paths become the intersecting lines which divided the region and finally become the plane. (Shirley Jo Probert. 2014, pp 24-25).

II. Shape

The various shapes could originate from the folding of the sub-planes in multi-direction, which would become the various shapes that constitute to the new form, as Dmitri Kozlov (2013) wrote that "The shape of architectural objects in general can be treated as envelopes: 2D surfaces embedded into 3D space. (Dmitri Kozlov. 2013, pp 253)

III. Proportion

According to the study by Katherine A. Liapi, it was found that the proportioning systems are crucial for the visual aesthetics, as the fundamental of division would be combined within the structure. For example, the golden ratio and other man-made geometric forms, which follow the example in the nature and re-arrange them to create the different beauty could be found clearly through the architecture and objects closed to human. (Katherine A. Liapi. 2002, pp. 80).

Generally, the standard solar panel layout design would be in the form of array facing sunlight at the spot with best average light exposure all day, after already considered the changing position of the sun although the year. The planar array would be without any curve nor tilting in other direction as shown in figure 6. However, the researcher started by laying each solar cell panel into grid with 6 row and 5 columns in this model, then used the calculation table to plan the tilting of each plane. The rotation axis would refer to the horizontal X and vertical Y axis. For example, the horizontal plane at X3 and vertical plane at Y3 would be tilted towards X,Y = 0,-15 degrees. And after the tilting angle of each plane was input into the table, the total tilting angle for all 30 panels could be shown as demonstrated in figure 8.

X / Y	1	2	3	4	5
	-30	-15	0	15	30
1 30	-30 / 45	-15 / 45	0 / 45	15 / 45	30 / 45
2 15	-30 / 30	-15 / 30	0 / 30	15 / 30	30 / 30
3 0	-30 / 15	-15 / 15	0 / 15	15 / 15	30 / 15
4 -30	-30 / -15	-15 / -15	0 / -15	15 / -15	30 / -15
5 -45	-30 / -30	-15 / -30	0 / -30	15 / -30	30 / -30
6 -60	-30 / -45	-15 / -45	0 / -45	15 / -45	30 / -45

Angle	15
Tilt X	0
Tilt Y	15

Figure 7. Standard solar panel which have flat surface intend to face against to sunlight. (Left)

Figure 8. Calculation table suggest for an angle of each planar surface should rotate. (Right)

From the above principles, the model was mainly designed to receive sunlight from morning until evening. Each pieces of solar cell may generate and compensate energy for each other, as each panel would be tilted towards different angle (figure 9). For an example, the model in this experiment was basically design for the observation site on Thursday 22th February 2018 (Summer season) at the top of a building close to Bangkoknoi canal in Bangkok, Thailand (13° 46' 44.3136" N; 100° 28' 9.012" E), which the solar noon period, or the moment when the sun appeared at the highest part of the sky compared to its positions during the rest of the day, was 12.33 PM. At that moment, the angular direction of the sun in the sky could be projected perpendicularly onto a reference plane (at an observer point) call True North-Based Azimuths, which equals 180 degrees from the north in this case (Figure 10), or around noon time.

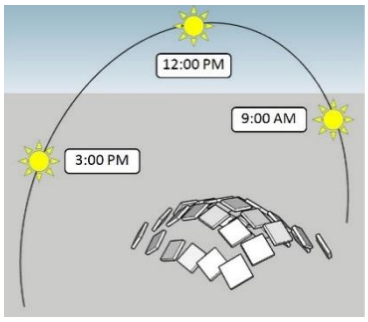

Figure 9. Shows 3D model of Solar cell position and facing to impact sunlight during day period. (Left)

Figure 10. Zenith angle of the Sun on Thursday 22th February 2018 in Bangkok, Thailand (13° 46' 44.3136" N; 100° 28' 9.012" E) in 12.33 PM (Right) - http://suncalc.net.

After tilting each panel to the desired angle, the researcher incorporated the curve plane so that the overall look of the model would resemble the earth's curve, in order to track the change of the sun's position in the north and south during the different season althrough the year. Figure 11 showed the front view, side view, top view, and perspective of the model. The top row was the regular image, while the below images were the model after the curve plane was incorporated. The overall look would be protuded up and allow the model to receive light in multiple periods.

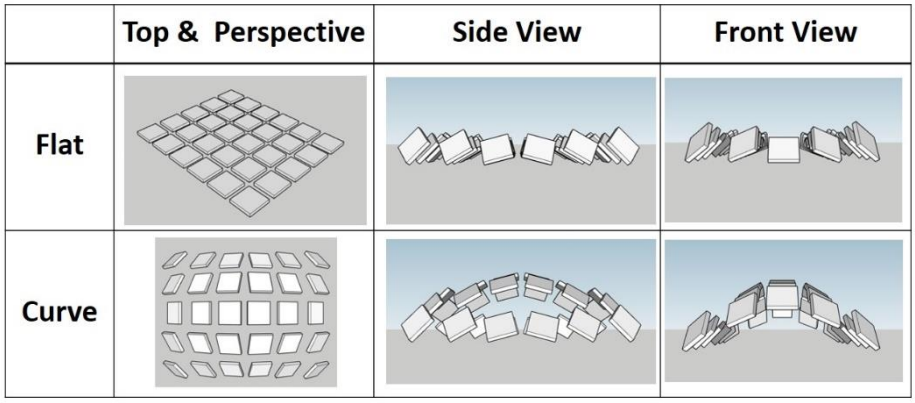

Figure 11. Design of model included curve of earth's surface plane in Front, Side, Top and Perspective view.

The curve in the X axis was designed to face the sun during the day, from dawn until dusk, which the sun would rise from the east towards the west at the end of the day. When looking from the top, the sun would seems to move from right to left. Therefore the tilting towards the sun in the X axis would allow the solar cell to be exposed to light in multiple period. Thus, the energy generation could be compensated this way

On the other hand, the curve in the Y axis was designed to face the sun during the year. As the earth's axis was tilted at 23.5 degrees, seasons could be observed when the earth's position was changed. When looking from the earth's surface, the sun's position would seems to move from the north to south. Therefore, the tilting towards the sun in the Y axis would allow the solar cell to be exposed to light in the wider periods in each month (or season) and could also compensate the energy production as well.

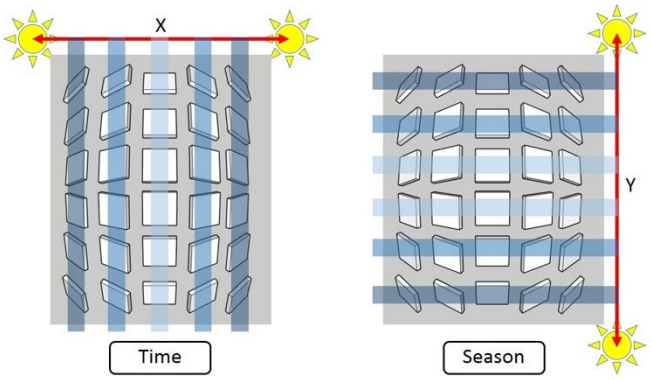

Figure 12. The curve of the layout would allow the wider period of light exposure, as the tilting in the X and Y axis served different functions.

The Model Construction

The solar zenith angle, or the angle between the zenith and the center of the Sun's disc for Thailand, which located at the coordinate 15.8700° N, 100.9925° E, would generally be around 15 degrees all year round (Waiyawat Saitum. 2016, pp. 260). Therefore, to avoid the regular layout of solar panels which face the sun in just one direction, it would be necessary to consider tilting the panels which would affect the exposure and energy generation. Previously, the researcher found that more FEV could be added for more complex shape by simple method of connecting two planar surface together the 15° / 15° tilting. When 5° was minus for the first one and 5° was added for the other, the surface then connected at 10° / 20°. In this case, the average of sunlight will share the incident on both planar surfaces as shown in figure 13. (Waiyawat Saitum. 2016, pp. 260).

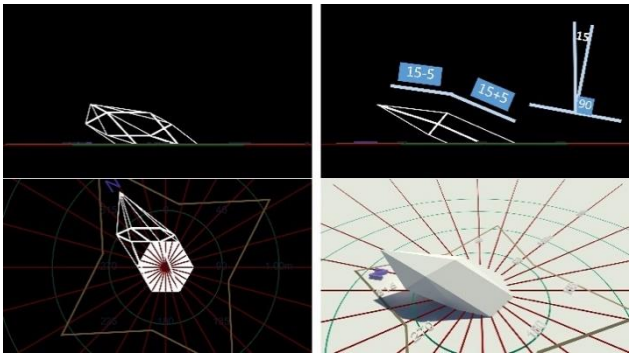

Figure 13. Shows 3D model develop for more complex shape.
(Waiyawat Saitum. 2016, pp. 260).

In order to proof the effectiveness of this design, a simple model was constructed with wooden base which was drilled in grid of 6 rows and 5 columns, with equal gaps between the grid. Afterwards, the researcher put the aluminum wire connected to the photovoltaic cell panel through each hole. The solar cell panel was 30x30x30 cm in size, with the adjustable joint which allowed the adjustment of tilting angle. The leg was also screwed to the wooden base so that the angle was tilted at 15°, in order to face the sunlight directly, as shown in figure 14.

Figure 14. Observation model upper-left : front view, upper-right : side view, lower-left : top view, lower-right : perspective view.

Observation

The observation process included data collection by the wattmeter at every hour starting from 9:00 – 15:00, on Thursday, February 22nd, 2018. The data was fluctuated due to the weather condition, which was partially cloudy and rainy as shown in figure 16. Therefore, the researcher added another observation day on Wednesday March 7th, 2018, and find the average data from both observation.

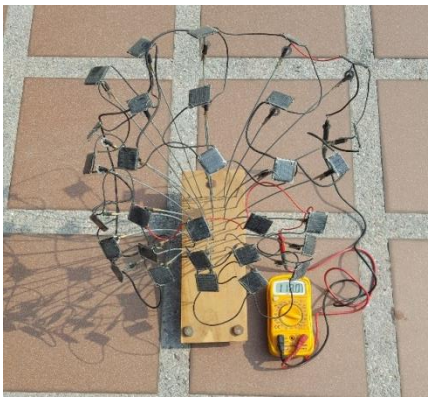

Figure 15. Exposing the model to the sunlight with wattmeter, in order to observe the design effectiveness. (Left)

Figure 16. The weather condition of bright sky and partial shade. (Right)

Solar Correction Data for Electric Power

Date / Time	Electricity	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	Average
22-Feb-18	V	6.40	6.49	5.89	6.80	6.35	6.66	6.19	6.40
	mAh	75.50	116.60	25.80	175.00	62.90	159.30	42.00	93.87
	Wh	0.48	0.76	0.15	1.19	0.40	1.06	0.26	0.61
07-Mar-18	V	6.43	6.50	6.54	6.62	6.65	6.63	6.49	6.55
	mAh	79.00	109.90	139.00	166.50	144.70	152.30	105.90	128.19
	Wh	0.51	0.71	0.91	1.10	0.96	1.01	0.69	0.84

* V=Volt / mAh = Milli Amp / Wh = Watt per Hour

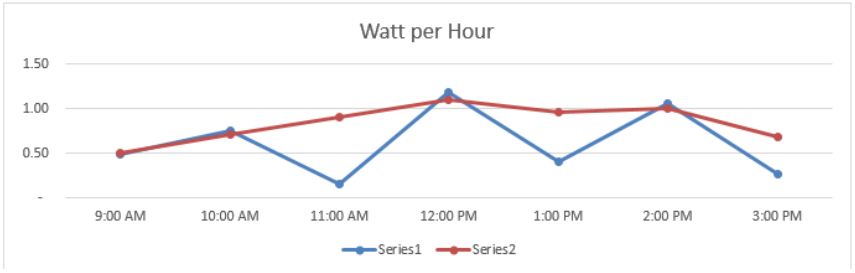

Table 1.The number of watt measured by wattmeter, with the unit of V, mAh and Wh

According to table 1, the electricity power was fluctuated on February 22nd, 2018 due to the cloudy weather condition, while the measured data on March 7th, 2018 was more stable. In both observations, the peak hour of energy generation was at noon, when the solar radiation intensity peaked. When calculate the measured current and voltage into watt-hour, the overall power was enough to run the prepared motor.

Experiment of Energy Usage in Art

Creativity requires complex thinking from various perspectives, active thought, initiation, flexibility, and details as well as connecting the relationship of things together. Only then could the new innovation could be created and led to the problem solving (Tichaponn Namwong, 2017, pp.20). Mixed-media art is a genre of visual arts which combine visual art materials together with other artistic disciplines, such as light, sound, movement, or olfactory object. Other visual art works which are above the mentioned criteria are also under the swift and continuous development, and might be called differently (Rewat Suksikarn, 2012, pp.6). Drawing is the most fundamental form of artistic expression which could be found generally in visual arts. Human usually draws by hand, holding the instrument such as pencil, pen, or brush. As the researcher attempted to combine the art and science together in order to explore the new possibility of artistic expression, the motor which was powered by the model mentioned above was connected to the brush pen. When the motor rotated, it also moved the pen. The researcher then adjusted the pen vertically and let it touch the paper as shown in figure 17. After a while, the drawing in figure 17 was generated.

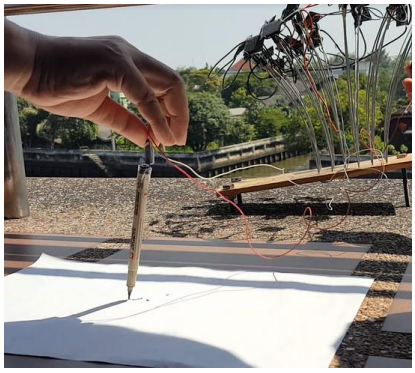

Figure 17. Connecting the model with the motor and the brush pen over the paper (Left)

Figure 18. Art work from the brush pen rotated by the solar energy (Right)

Results and Discussion

I. Solar energy factors

a. The coordination on the map of the site where the sculpture would be installed should be considered. As each site would be in different location, the coordination would affect the direction of light from the sun, which would also affect the installation of the sculpture.

b. The electric component's requirement of energy power must be responded, for the component would not work or would not be efficient if the power is not enough. Therefore, the current and voltage needed should be considered, which would affect the choice of the suitable solar cell panel.

c. There are various types of solar cell panel in the market, with different sizes, qualities, and prices. Each type of solar cell would be suitable to the different needs. Therefore, the appropriate type, current, voltage, size, and amount of solar cell panels should be considered, especially the size and the amount of the solar cell panel which would directly affect the sculptural form.

II. Sculptural design factors

a. Materials of the sculpture which incorporate the solar cell panel should be resistant to moisture, rain, dew, wind, sun, and heat, etc., as the sculpture would be installed outdoor. If this factor is overlooked, the sculptural would be easily damaged. Therefore the material should be quite durable, depending on the sculpture lifespan desired

b. The location and direction of the sculpture installation must be studied, in terms of the coordinate, latitude and longitude, in order to find the suitable average angle of the Solar Zenith Angle for each site. Moreover, it would suggest the direction which the sculpture should face. Generally the sun would rise from the east towards the west. Different latitude could also affect the changes in the season, atmosphere, daytime, nighttime, and solar radiation, etc. The same original model shape could be change into various art forms up to the reasons above. (Waiyawat Saitum. 2016, pp. 260).

c. The planar surface of the sculpture which could be in various shape could be divided in two parts; the part which would be exposed to the sunlight, and the part which would not be exposed to the sunlight. The direction and the angle of the planar surface exposed to the sun must be considered. The power received in each hour of the day should also be monitored, in order to know the time when the sunlight exposure would yield the maximum and minimum power.

Conclusion

The usage of solar cell panel for electricity generation in sculpture had both advantages and limitation, which would be described below.

I. Advantages

a. It would be the application of technology in the work of art, which led to the combination of the modern design and the widespread variety of the work of art.

b. The solar energy is about the functionality, while the sculpture is about aesthetic. When both things are combined, the art work could also serve both the physical and aesthetic function of the human's daily usage.

c. The work could be the inspiration for both the artistic and scientific world. The designers or artists could further develop the concept into painting, sculpture, or any other new products with the solar energy function. The scientist related to the solar cell development could also gain some insight in order to develop the new type of photovoltaic cell which could better serve the artistic production instead of the mere generation of solar energy.

d. As energy is highly important to the daily consumption nowadays, incorporating the solar cell as a part of art and design should partially respond to the basic need for daily life, such as cooking, lighting, and communication, etc.

II. Limitations

a. There would be the limitation in design, as the solar cell must be exposed to the sunlight in order to generate electricity, therefore the sculpture must be installed outdoor and required the material to endure all type of the weather conditions in the different environment.

b. The built sculpture might have less lifespan due to its being placed outdoor as previously mentioned. Thus, the lifespan might have to be designated from the beginning in order to select the appropriate material. For example, the long lifespan over 10 years would require the use of stone or metal, while sculpture of medium lifespan below 10 years could be built of hard wood, fiberglass, cement, or steel structure. Finally, the temporary sculpture could even be created from plastic, rope, clothes, or paper.

c. The wiring of the circuit must incorporate the process to prevent moisture and heat to affect the solar cell panel, or else the circuit could fail, which would stop the component from working effectively.

d. Some work of art might be designed to last for a long period of time, while the electronic devices might not last as long due to their level of fragility. Although the component's fragility would depend on many factors such as quality, assembly, damage prevention such as moisture-proof system, but the component's efficiency would still be decreased overtime, until it might stop working while the sculpture could still last.

e. The design which must follow the direction of light would require the form and shape of the sculpture to be manipulated in order to match the solar cell's requirement of light exposure. Therefore, the design would be limited and required the sculptor to solve the problem and adjust the design, that the final result might not resemble the original intention.

f. The application of electricity from solar cell would depend on the sunlight as an important factor. Without the sunlight, the component would not work, unless the battery which could store the electricity power for further use in the time when sunlight is not available. However, the battery could fail due to the moisture, as the sculpture must be installed outdoor.

Innovations

This study yields the new approach which could be further developed into many other applications. The sculpture from could be changed by rotating, scaling, and moving three types of elements which were the planar facets (F), linear edges (E), and point vertexes (V) according to the desired topology. The more complex manipulation of the element, the more possibility of aesthetic could the sculpture become. However, the manipulation of form must be done with careful consideration, for it must also follow the sunlight-related factors such as different latitude, environment, and period. (Waiyawat Saitum. 2016, pp. 262).

I. The design of new forms could be accomplished with the FEV design fundamentals, which would allow the designer to achieve more type of surfaces. The design would be more complex from the original prototype and could follow the concept with the desired level of curve or smoothness. But as the solar zenith angle must be considered in the calculation of the planar surface tilting, the form would require crystallization as shown in figure 19.

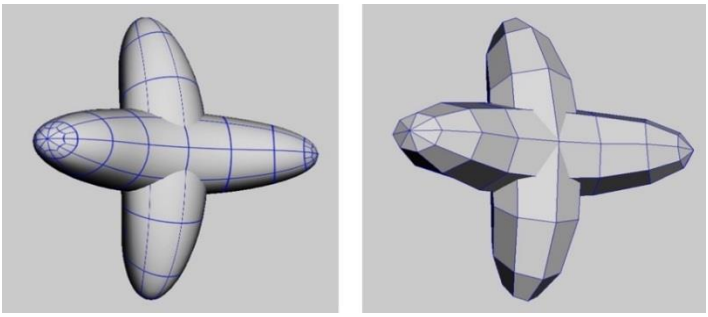

Figure 19. The design of more complex sculpture while considering the solar zenith angle. The left picture illustrated the example of free form designed, while the right picture demonstrated the crystallization.

II. The major limitation of the sculpture design for sunlight exposure is that it could be exposed to light from the top direction only. This problem could be solved by placing the mirror underneath the sculpture to reflect the light towards the sculpture plane, which might allow the sculpture to generate twice more energy. This technique of using mirror to reflect the light could also allow the sculpture in shady area to be exposed to the sunlight and generate electricity. Or in the case of the sculpture which would be installed over the water, the reflected light from the water surface might also allow the surface plane underneath the sculpture to generate electricity. However, it would require more study about the reflection of the moving water surface which would be different from the regular mirror.

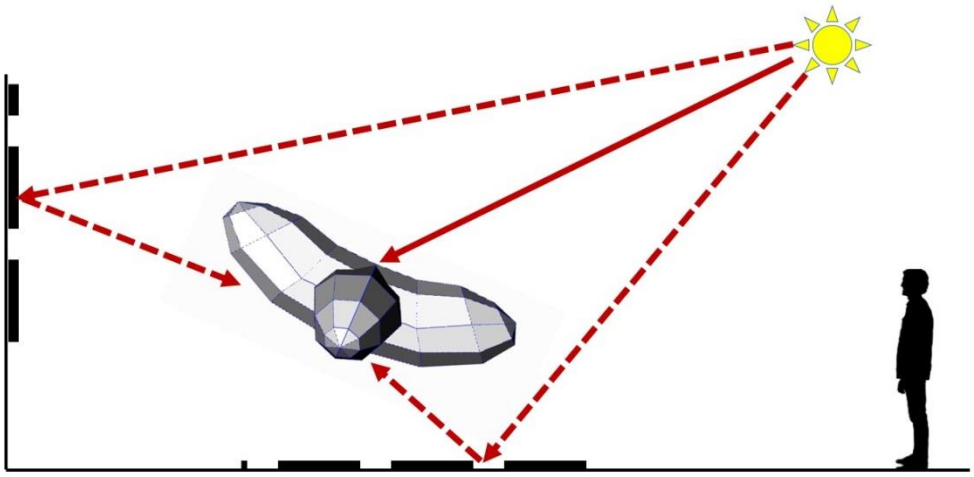

Figure 20. The reflection of sunlight onto the sculpture surface in shade.

III. If the sculpture could generate electricity by its own, the energy application could be used for both outside the sculpture and with the sculpture as well. Therefore, the sculpture could be developed into kinetic arts, or the art works consisted of movable parts or movement driven by the electric power.

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