ADAPTIVE DECORATIVE BUILDING SKIN

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Abstract. Traditional decorative ornaments were commonly used on the building skin of traditional architecture. Nowadays in urban areas, those ornaments become less popular for they are considered old-fashioned and due to the lack of technical function that matches with the modern building designs. Based on those issue, this paper proposed a type of building skin that aimed to revive a new expression of traditional decorative elements by applying digital design tools and technology as well as having an adaptive function. Traditional decorative ornaments merged in an adaptive skin that used traditional patterns as a controller of the effect of environmental changes in a building could provide a new expression of the use of traditional ornaments on a building in accordance with the times. Most of the adaptive building skin used kinetic techniques in order to make its formation and pattern transformable. This paper proposed a parametric-cam mechanism to transform the pattern of traditional ornament using pre-programmed analysis data of environmental changes to parametrically drive the number of rotation phase and length of nose that generated the shape of the cams. In conclusion, this paper has developed a prototype tool that facilitates the new approach to kinetic decorative ornaments on building skin.

Keywords. Decorative ornaments; adaptive building skin; camshaft mechanism; kinetic building; building technology.

1. Introduction

Several national strategic areas that require intensive research to undertake various challenges of the nation have been declared (Tri, 2012). One of the areas is on arts and culture, creative industry, and culture technology. The strategic issue stated was the lack of development based on local wisdom and uniqueness, for example the lack of local specialty or expressiveness. Based on those issue this paper proposed a type of building skin that aims to
revive a new expression of traditional decorative elements by applying digital technology as well as having an adaptive function. Traditional decorative ornaments merged in an adaptive skin that uses traditional patterns as a controller of the effect of environmental changes in a building may provide a new expression of the use of traditional ornaments on a building in accordance with the times.

In most of the time within a year, the sky illuminance in the tropical climate is extremely high (>10,000 lux), therefore one of the function of building skin in traditional housing are used to control the lighting levels. Correspondingly, building skin is also used to express symbolical ornament or aesthetical preferences. Consequently, the ideal standard of visual comfort in most cases could not be achieved. Most of the daylight levels in traditional housing are below the standard of visual comfort.

With the use of adaptive building skin that could maintain the visual comfort. The nature of the adaptive building skin is that it can adapt to changing environmental conditions such as the changing sun path. Changes in the movement of sun per day and per year resulting in daylight levels received at any part of the grid surface of the building to be always changing. By applying an adaptive building skin solutions that specifically follows the changes in every part of the surface will be able to maintain the standard of visual comfort.

In order for every part of adaptive building to be able to move, large numbers of motors, sensors, and drivers are used. In order to operate that equipment requires electrical energy. Even with the use of photovoltaic, high costs will be required to produce such a device. Furthermore, mechatronics equipment, especially motors, has limited period of use, therefore the cost for maintenance and replacement of equipment will contribute to the high expenditure, and this will result in the overall energy inefficiency and the level of sustainability to be achieved can be very low.

Mostly, the applications of adaptive building skin are applied on high profile projects or expensive buildings and rarely on common housing. Therefore, this study also proposed a system that could reduce the kinetic mechanism problems of the above issues in order to lower production costs, save energy consumption of the appliance and maintenance by applying parametric camshaft methods. By using this method the amount of motor usage at each grid could be reduced and make it more centralized, this method could also reduce the number of motor drivers, and replace the use of sensors with environmental analysis data values.
2. Related research

There has been a growing interest to include intelligence in buildings to be energy efficient. Smart architectural design decision or intelligent technological devices can do this. Their defined active features are elements of buildings, which can self-adjust to the changes initiated by external environment (Ochoa and Capeluto, 2008). By actuating the facades and making them dynamic, they can now better adapt to the conditions and provide for improved comfort of the occupants. Facades can now sense the environment and make their own modifications in order to achieve prescribed goals. The building can be constantly working towards a better environment for the user as opposed to simply protecting them from it (Hansanuwat, 2010). By studying the many existing kinetic building skin systems and through the use of computer simulations and empirical testing, a sampling of the methods of kinetic movement can be analysed for their environmental benefits, compared to each other, and recommendations proposed (Skavara, 2009). Parametric design method can effectively make the building modelling and its configuration connected to the real world climatic parameters, and facilitates the study of building sustainability related to energy efficiency and it also offers an important way to explore the kinetic building components (Wang and Li, 2010).

The above researches have described that the mainstream drivers for adaptive and kinetic building components are sustainability and energy efficiency, however the adaptation of high-tech envelopes has been slow, sceptical architects foresee them being unplugged and later stripped off their building due to poor performance, broken actuators or deficient maintenance, plainly the road to the interactive envelope is a rough one (Sullivan, 2006).

These studies and literatures of kinetic and adaptive building issues present our research with the practical and sustainable insight into how to explore and manage the building envelope behaviours to the environment. The originality of this paper is to develop new system for adaptive skin to be more energy efficient and more widely used, in order to increase the number of green buildings.

3. Methods

Daylighting simulation at a specific location has been conducted to produce the values that will set the parameters of the adaptive skin. Location setting was in Jakarta, Indonesia (6.16 S, 106.48W), and the weather data was taken from 2010. Climatic condition at this location is tropical. Weather changes in a year is not too drastic, therefore this study will focused on the controlling of changes per hour in 1 day. The analysis data were taken on March 21, June 21, September 23, and December 22, on 09:00 AM 12:00, 15:00.
The study was conducted as follows, firstly this study focused on adaptive skin that was conducted by analysing daylight levels to find the appropriate opening angle and obtain effective visual comfort requirements. Furthermore, the analysis result of adaptive skin study was used to generate kinetic mechanism using parametric camshaft method (Sjarifudin, 2012).

Since the location was on the southern hemisphere, the building orientation for this study would focus on the South, Southwest, Southeast, and North side. The next study was to determine the model of room and shading device. The room model was set to the average housing dimension (width: 6m, length: 9m, height: 3m). The dimension of shading device was set to fit the unit facade (3x (2m x 3m)), and the fin was: 2m x 50cm. The daylight level was measured at the height of the working plane, in this study was set at the height of 60cm, and the depth of 450cm.

The study of adaptive skin was initially conducted by comparing facade without any shading, and with vertical / horizontal types of shading, the result of the simulation showed that the use of shading on a unit could lower the intensity of light coming into the room and the use of horizontal shading could reduce the intensity of light coming into the room higher than vertical shading. Figure 1 shows the comparison of daylight simulation using vertical and horizontal shading.

Following study was conducted to find the suitable shading angle for South, Southwest, Southeast, and North orientation of the units. Table 1 showed required daylighting levels on each time and building orientation, from the effect of different shading angles.
From the daylight level analysis at the time of building units facing South, Southwest, Southeast, and North before using shading was 950 lux but using shading could reduce the level of daylighting. Angles were used in this study to meet the standards requirements from 350 to 750 lux.

On 12:00 AM Building facing South and North should use an opening angle of 30°. When using angles smaller than 30° the daylight level in the room could exceed the standard requirement.

On 3:00 PM Building facing southwest should use an opening angle of 45°. When using angles smaller than 45° the daylight level in the room could exceed the standard requirement.

On 9:00 AM Building facing Southwest should use an opening angle of 45°. When using angles smaller than 45° the daylight level in the room could exceed the standard requirement.

<table>
<thead>
<tr>
<th>DL Standard</th>
<th>Building Orientation</th>
<th>Daylighting Levels on 1st floor</th>
<th>Daylighting Levels on Desk Height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>09:00</td>
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<tr>
<td></td>
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<td>Shading Angle</td>
<td>Lux</td>
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<tr>
<td>750 Lux</td>
<td>South</td>
<td>450 - 950 15°</td>
<td>450 - 950 30°</td>
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<tr>
<td></td>
<td>Southwest</td>
<td>450 - 950 15°</td>
<td>450 - 950 30°</td>
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<tr>
<td></td>
<td>Southeast</td>
<td>550 - 950 45°</td>
<td>450 - 950 30°</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>450 - 950 15°</td>
<td>450 - 950 30°</td>
</tr>
<tr>
<td>600 Lux</td>
<td>South</td>
<td>350 - 850 30°</td>
<td>250 - 950 45°</td>
</tr>
<tr>
<td></td>
<td>Southwest</td>
<td>350 - 950 15°</td>
<td>350 - 950 45°</td>
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<tr>
<td></td>
<td>Southeast</td>
<td>250 - 950 60°</td>
<td>350 - 950 45°</td>
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<td></td>
<td>North</td>
<td>350 - 850 30°</td>
<td>250 - 950 45°</td>
</tr>
<tr>
<td>500 Lux</td>
<td>South</td>
<td>250 - 750 45°</td>
<td>350 - 750 60°</td>
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<tr>
<td></td>
<td>Southwest</td>
<td>250 - 750 30°</td>
<td>250 - 750 60°</td>
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<tr>
<td></td>
<td>Southeast</td>
<td>350 - 650 60° &amp; 75°</td>
<td>350 - 750 60°</td>
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<td></td>
<td>North</td>
<td>250 - 750 45°</td>
<td>350 - 750 60°</td>
</tr>
<tr>
<td>350 Lux</td>
<td>South</td>
<td>150 - 450 60°</td>
<td>150 - 550 60° &amp; 75°</td>
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<td>North</td>
<td>150 - 450 60°</td>
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Furthermore, detailed analysis on the shading device formation changes of its fins was conducted and 8 different shading (fin) formation was found. Table 2 showed these formation would be used accordingly to adapt to the changing daylight condition throughout the day. Based on these formations, further study on the mechanism was conducted in order to develop simplified model of the adaptive shading using parametric camshaft method.

4 Parametric camshaft study

4.1. CAMSHAFT VS PARAMETRIC CAMSHAFT

This study used camshaft as a mechanism for controlling kinetic movements of adaptive skin system. Camshaft is a shaft to which a cam is fastened or of which forms an integral part, where a cam is a rotating piece in a mechanical linkage used specially in transforming rotary motion into linear motion. The integral parts of a cam are Base circle, Nose, Lobe lift, and Duration (Figure 2). These parts are used in this study as the modules in generating parametric camshaft.

![Figure 2. Cam profile used on a car engine.](image-url)
4.2 PARAMETRIC CAMSHAFT

What distinguish the parametric camshaft in this study are the use of multiple Nose and Lobe lift on each cam. This will result in a non-linear movement and changes. The cam will control the size of the openings of each fin of the shading system.

The main parameters in the parametric camshaft are the length of Lobe lift (L) and the number of Duration (P). Each L and P has different values, and the values are determined from the result of shading angle study. Figure 3 shows the profile of parametric cam and non-linear movements it can generate.

![Figure 3. Parametric Cam profile applied in each fin of adaptive shading system.](image)

The result of angle study was used to generate shape of parametric camshaft. The smallest angle was 150 and the biggest was 750, these values were then used as a parameter determining the minimum and maximum length of L and the number of P. To be able to produce the calculations and parameter settings, this research used algorithmic editor software Grasshopper which is a plug-in for CAD software Rhinoceros. Figure 4 shows the screenshot of the parametric relationship made in Grasshopper.

The algorithm made for controlling the fin was: The smaller shading angle would produce a small value of L that led to a mechanism to close the fin, while the higher shading angle would produce a large value of L that led to a mechanism to rotate the fin.
Then, the significant number of changes in daylight level would be used as a determinant of the number of P in a single cam. In this case significant changes in the value of radiation on one shading unit were 5 times, therefore the number of P=5 Figure 3 showed variation of L and number P in each cam.

Figure 4. Parametric control and component relationship in Grasshopper.

Furthermore, the incorporation of cam rotation with specific shapes and driver mechanism would result in angular movements that varied according to the length of L and the number of P.

Furthermore, a motor would drive the operation of each camshaft. Each camshaft would be driven by a servo motor that rotated according to the number of P. Full turn (360°) would be divided by the number of P that operated for 12 hours, then off for 12 hours. These settings were done in the microcontroller that collected input data from Grasshopper (Figure 4) with Firefly plug-in that connected the data from Grasshopper to microcontroller to drive the servomotor. Figure 5 showed fundamental prototype development of parametric camshaft.

Figure 5. Cam rotation movement with 6 changing phases (left), and simplified prototype of parametric camshaft (right).
Finally, the whole shading each with own specific camshaft were applied to the fins of the adaptive skin. For one day the surface of this shading system would constantly change to follow the daylight changes.

These fins would be moved to reveal different patterns and inherently creates an interval of closed surface to opened surface that controls the effects of adaptivity. The amount of opening was determined from the length of L of the cam that has been adapted from the traditional pattern (Figure 6).

![Figure 6. The openings from adaptive skin](image)

**5. Conclusion**

This research has shown the use of parametric camshaft for controlling kinetic mechanism in adaptive building skin system. The affectivity of this system was observed more enduring in two-season climatic conditions whereas not many changes in environmental conditions occurred during the whole year. For example, if the buildings in the tropical countries used adaptive building skin system designed for four-season climatic conditions, there would be much dissipation, and the efficiency and benefits that could be obtained at the four-seasons countries would not be as much compared with the amount of energy required for operation of the system. In terms of cost-reduction, the application of this system on general buildings (non-high profile building) could be applied, so that more users could experience the benefits and advantages of adaptive building skin system.

Further research will be focused on the application of materials and assembly. The aim of research is finding the effective materials in terms of durability, cost, methods of easy assembly and maintenance. Other plans for further research is to build a physical prototype with 1:1 scale. This prototype will be tested on the actual environmental conditions to conduct some adjustments and other findings that could improve the efficiency and effec-
tiveness of this system. The main targets for these researches are to achieve higher level of sustainability and energy efficiency of an adaptive building component that can also express traditional decorative ornaments.

References


