Developing a Kinetic Façade towards a Solar Control Façade Design Prototype

Walaiporn Nakapan* and Apiwat Siripattanamongkol

Faculty of Architecture, Rangsit University, Pathum Thani, Thailand
*Corresponding author, E-mail: walaiporn@rsu.ac.th

Abstract

This paper presents an early development of a kinetic façade prototype. This Arduino project is developed after a request of an aluminium profile company in Bangkok. The company would like to study a possibility to develop aluminium fins into a kinetic façade that adds value to their product. Even though the initial development of this kinetic façade is for an aesthetic purpose, we see a potential of this prototype for a solar control purpose. Therefore, this paper presents 3 steps of the early development of the prototype as proof of the concept: Step 1: Get building requirements; Step 2: Prototyping the kinetic façade; and Step 3: Sun shading analysis of the façade. As a result, the prototype has shown the fins movement; the Arduino driven fins are able to move in an aesthetic sequence. However, the sun shading function of the kinetic façade is shown on the Rhino-Grasshopper simulation only, and not yet programmed in Arduino. The benefit of this prototype and its future development for a sun shading purpose will be discussed.

Keywords: *Kinetic façade, solar control, arduino, parametric design*

1. Introduction

1.1 What is a kinetic façade?

Just like the human body has got a skin, a building has also got a skin or an envelope. And the principal exterior envelope of a building that faces onto a street or an open public space is called a façade. A kinetic façade, more specifically, is one that changes dynamically rather than being static or fixed, thus allows movement to occur on a building's surface (Kinetic facade, 2018). This is a branch of kinetic architecture that focuses on the physical exterior movement of the building enhanced by a mechanical system. The concept of kinetic façade is about applying geometrical transformation to create a movement in space (Velasco, Brakke, & Chavarro, 2015); these transformations are:

1) Translation: the object is moved from one place to the other,
2) Rotation: the object is rotated around all axis,
3) Scaling: the object is resized, enlarged or contracted,
4) Motion through material transformation: this motion depends on the elasticity of the material.

A kinetic façade is described by Buckminster Fuller, an American architect with a forward-thinking mindset, as a 'skin-like articulation' (Salter & Sellars, 2010). Façade elements can be programmed to respond to climatic factors, to improve energy efficiency, to reduce solar heat again, or for aesthetic reasons as an art installation or to act as a live signage, etc. (What are kinetic facades in architecture?, 2015).

1.2 Examples of kinetic façades

In the 1940s, Buckminster Fuller began experimenting with kinetic façade with concrete implementations, though his early efforts are not regarded as totally successful (Salter & Sellars, 2010). Until 1987, an innovative example of a kinetic façade has arisen: the Arab World Institute in Paris by Jean Nouvel. The French architect uses the advanced metallic brise soleil on the south façade. This light sensitive diaphragm, which was inspired by the Arabic motifs, was used to regulate the amount of daylight and heat that enters the building (Winstanley, 2011). Since then, we have seen numerous kinetic facades that combine the sense of aesthetic and advanced technology, such as the SDU Campus building in Kolding, Denmark by Henning Larsen Architects where the dynamic solar shading adjusts to the specific climate conditions and provide optimal daylight and comfort for the indoor space (SDU Campus Kolding / Henning Larsen Architects, 2015); In Brisbane Airport parking garage by Ned Kahn, Hassell Architecture

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and UAP, the architects used suspended aluminium panels that change pattern with the wind, creating a fluid façade (Caula, 2012). The Al Bahar Towers Responsive Façade, Aedas Architects designed a responsive façade to combat the extreme weather of Abu Dhabi. Computer controlled, the façade panels act as a shading device that can open and close like an umbrella (Cilento, 2012). A recent renowned project is the Bund Finance Centre in Shanghai by Foster+Partners and Heatherwick studio; the kinetic façade that creates the link between the interior and the exterior of the building, is composed of 675 individual metal tassels on three tracks. Inspired by the Chinese pattern, when the tracks move around the perimeter, the tassels overlap and changes its opacity and aperture, thus constantly create new patterns (Heatherwick Studio, 2010) (cf. Figure 1).

Figure 1 The Bund Finance Centre, Shanghai by Foster+Partners and Heatherwick studio, photo by Walaiporn Nakapan

1.3 Previous research

There is quite a number of literature on kinetic façade; one of them is a paper by Cheol-Soo Park et al. (2004) who studied the calibration of a simulation model of double-skin façade systems with controlled rotating louvers and ventilation openings. In Thai context, a work by Srisak Phattanawasin and Prittiporn Lopkerd (2016) proposes the innovation of automatically adjustable sun louvers with real-time solar tracking systems. Another work by Kanin Srinoradithlert, Santirak Prasertsuk and Chawee Busayarat (2018) took a technological approach, as they proposed a design guideline for automatic façade controlled by smartphone application for a regulation of natural light.

2. Objectives

M.P.V. Four Stars, Co.,Ltd. is an aluminium profile company in Bangkok (cf. Figure 2-left). The company is committed to developing green products that is environmental friendly or helps protecting the environment. Figure 2-right shows an initiative of the company to develop an adaptable fin using a hand rotating device. The company recently has been commissioned to install aluminium fins on facades of a high-rise building. The company then asked our team to study a possibility to develop aluminium fins into a kinetic facade that adds value to the company's product.

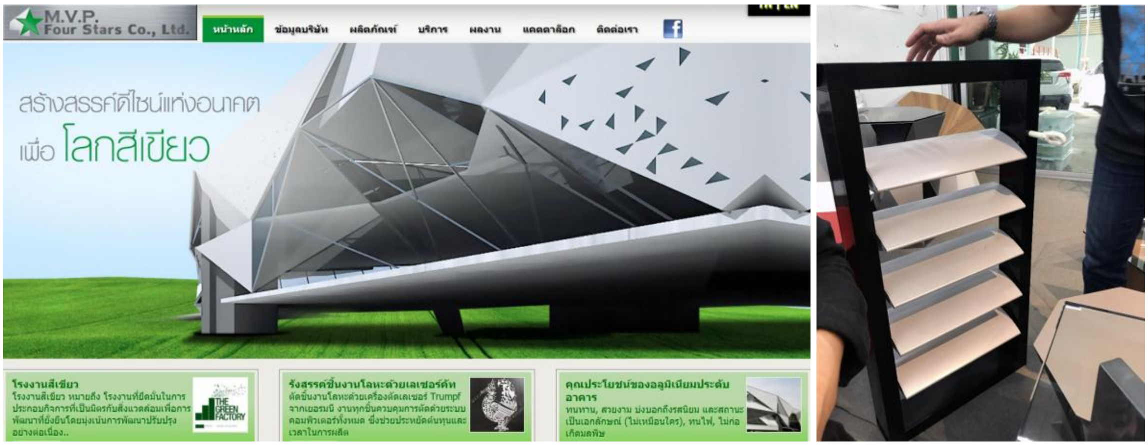

Figure 2 Website of M.P.V. Four Stars, Co.,Ltd., an aluminium profile company in Bangkok (left), an adaptable fin using a hand rotating device developed by M.P.V. Four Stars, Co.,Ltd. (right)

A question was asked: "Is it possible to make a kinetic façade made of numerous adaptive aluminium fins?". The objectives of this research is:

1. To develop a kinetic façade prototype as a proof of concept to demonstrate an aesthetic point of view,
2. To do a sun shading analysis of the façade through computer simulation.

3. Materials and Methods

3.1 Development steps

The actual development of a kinetic façade consists of 5 steps:

- Step 1: Get building requirements,
- Step 2: Prototyping the kinetic façade,
- Step 3: Sun shading analysis of the façade,
- Step 4: Calculation and choosing motor size,
- Step 5: Façade mock up before installation.

However, this paper presents an early development of the prototype that corresponds to step 1-3 as a proof of concept. It is an Arduino project whose material consists of an Arduino board, a micro-controller, to drive 3d-printed fins to move on a mock-up building.

3.2 Step 1: Get building requirement

A drawing is given by MPV Four Stars Co., Ltd., showing aluminium fins installation and building dimension (cf. Figure 3).

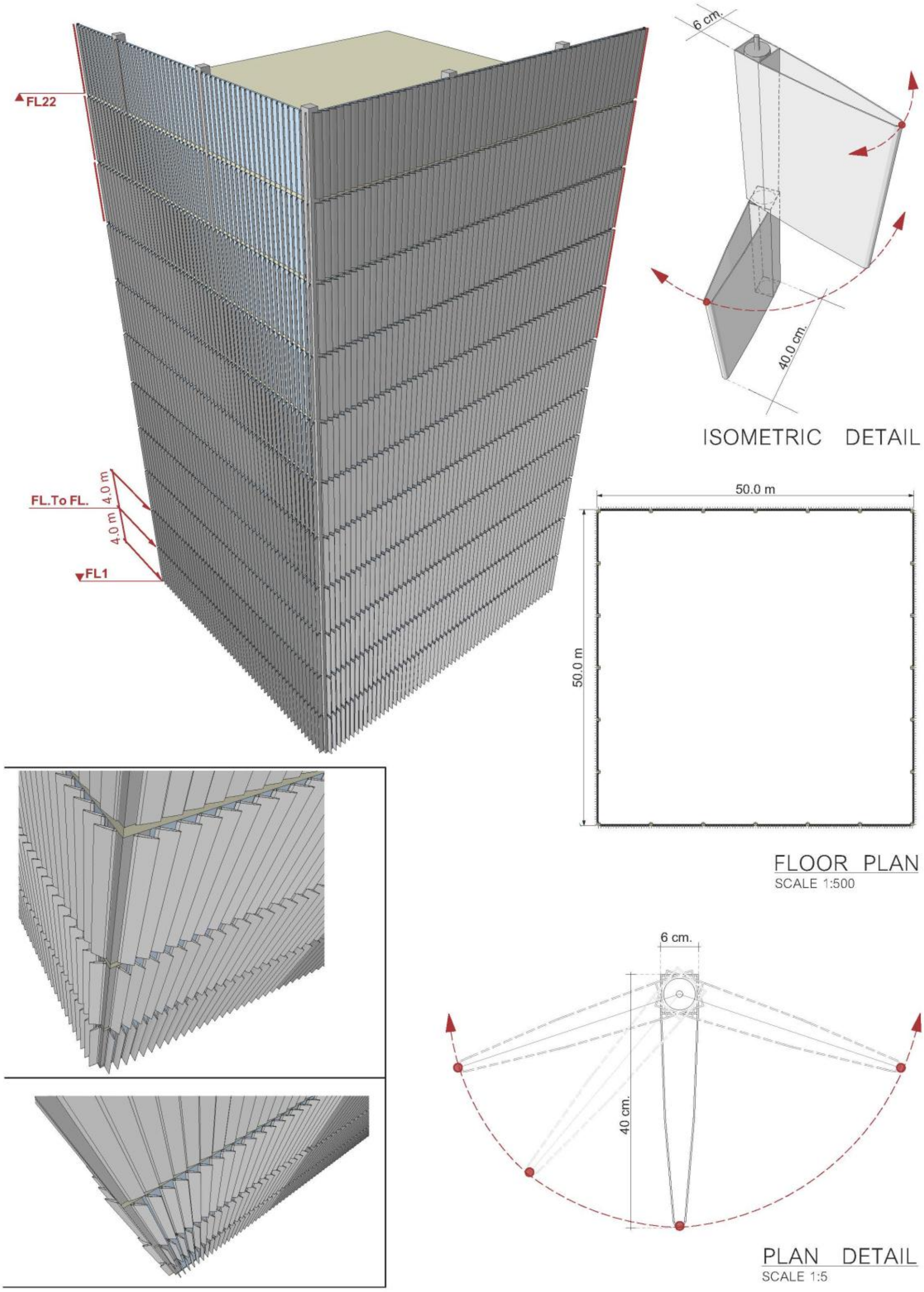

Figure 3 A drawing showing aluminium fins installation and building dimension

- Abstraction of the model

The prototype is an abstract model of the building, with only 1 floor and 2 sides of façade: the West and the South façade. The floor plate size of the actual building is 50m x 50m; it is scaled down by 1:100 to 50cm x 50cm. The fin size is widened from 40cm to 80cm at 1:100 scale for clearer visibility and easier implementation, and the number of fins is reduced by half - from 40 to 20 fins on each side. Therefore, it leaves more space between each of them, which is suitable for installing servo motors.

3.3 Step 2: Prototyping the kinetic façade

There are two ways to move fins:

1) using gears: a single motor drives the gear that is connected to the fins. A gear can move all fins at once; this approach doesn't need many motors to drive the fins, but the fin movements are restricted to a fixed pattern.

2) using separate motors: a fin is driven by a single motor. This approach needs many motors, consumes a lot of energy but give a freedom of movement to the fins. It is also possible to program the movement in many different ways. In this research we use this approach to show the possibility of movement of a kinetic façade.

- Prototype mock up model

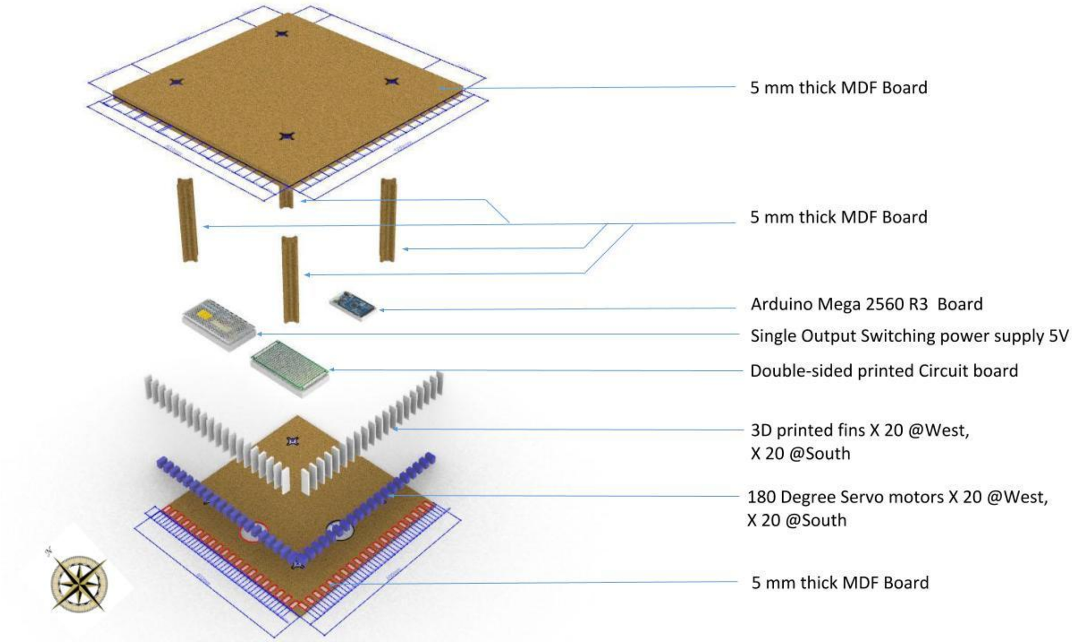

Figure 4 Components of the prototype

As shown in Figure 4, the prototype consists of:

- Two 5 mm thick MDF Board,
- An Arduino Mega 2560 R3 Board,
- A Single Output Switching power supply 5V,
- Q Double-sided printed Circuit board,
- 40 - 3D printed vertical fins: 20 for the West facade, and 20 for the South facades,
- 40 - 180 Degree Servo motors: 20 for the West facade, and 20 for the South facades.

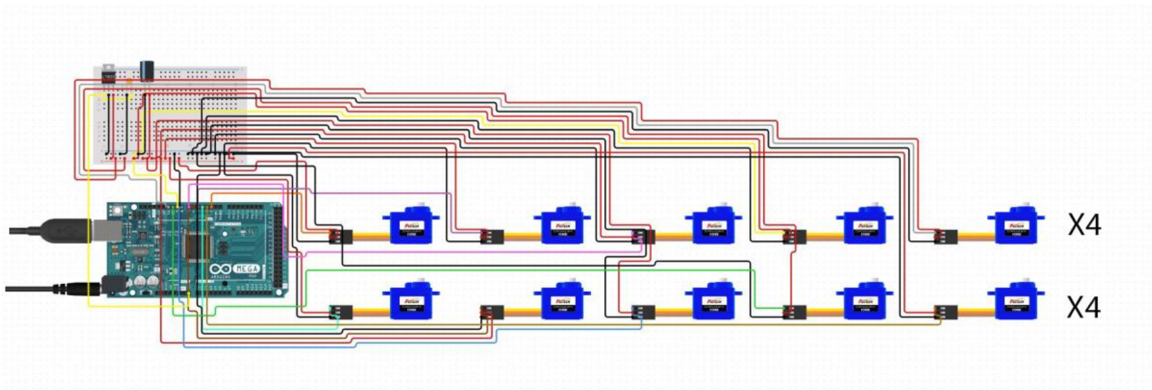

Figure 5 Arduino circuit board diagram

- Arduino circuit board mock up

Figure 5 shows Arduino circuit board diagram (the number of servo motors is reduced by 1/4 for legibility). The Arduino Mega R3 board is wired to 40 servo motors; a MegaServo Hardware Servo library file called “MegaServo.h” is needed in order to be able to attach up to 48 servos to the board (Arduino Mega only, other boards support up to 12 servos) (MegaServo Hardware Servo library, n.d.).

The prototype is developed at Idea Factory, a digital fabrication lab at National Yunlin University of Science and Technology (YunTech), Taiwan. The MDF boards are cut using a laser cutting machine, and the fins are 3D printed. Due to the large number of wires and pieces, servo motors and their corresponding circuit wires need to be numbered (cf. Figure 6 –left).

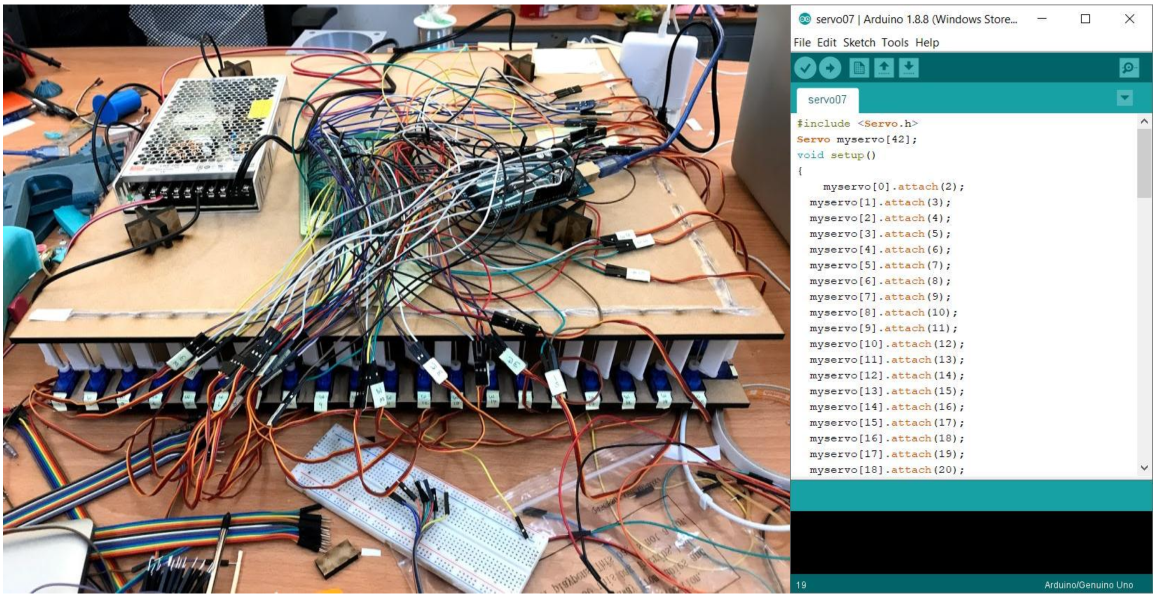

Figure 6 Left numbered pieces in the mock up, right – programming in Arduino language

- Programming of an aesthetic sequence:

A wave sequence of the fins are programmed using Arduino programming language (cf.Figure 6 -right).

3.3 Step 3: Sun shading analysis of the façade

There are a few possibilities to implement a solar control on a kinetic façade, such as:

- the fins movement is responsive to daily sun paths to maximize shading and views,
- the fins movement is responsive to light sensors to maximize shading and views,
- the fins movement is responsive to daily sun paths with feedback loop using light sensors to maximize shading and views.

In this research, the first approach is simulated using Arduino, but the Parametric simulation is done in Rhino-Grasshopper only. This prototypes show the blades movement is responsive to daily sun paths to maximize shading and views using these key dates:

- Winter solstice: 21 December (Sun most southward),
- Equinox: 21 March, 21 September (Day/Night equal hours),
- Summer solstice: 21 June (Sun most northward).

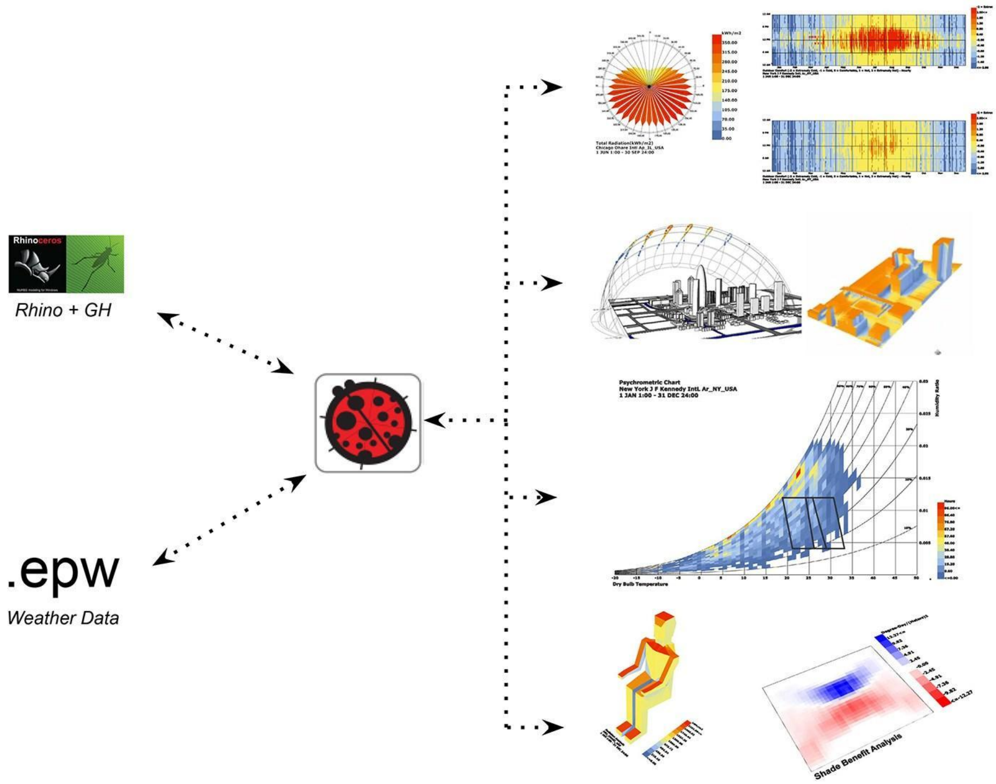

Figure 7 Grasshopper's lady bug add-on

Grasshopper's Lady Bug add-on uses Weather data file (.epw) to analyse sun path and sun shading. The .epw weather file is one of Bangkok at the latitude 13.4 Degree North. The sun path is calculated using hourly data of the sun position in one calendar year. The fins are programmed to rotate at a 90 degree angle to the solar azimuth angle in order to provide maximum shading.

4. Results and Discussion

The prototype has shown the fins movement; the fins are able to move illustrating an aesthetic sequence (Figure 8).

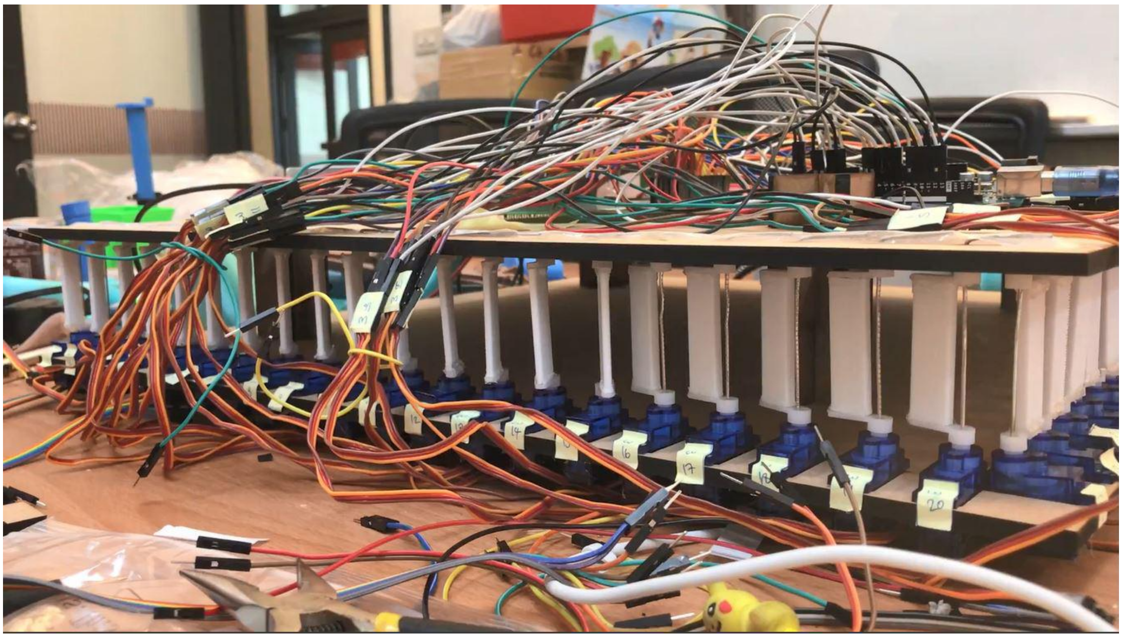

Figure 8 A screenshot showing an aesthetic sequence of the fin movement

However, a simulation of the kinetic façade is shown on the Rhino-Grasshopper simulation (cf. Figure 8)

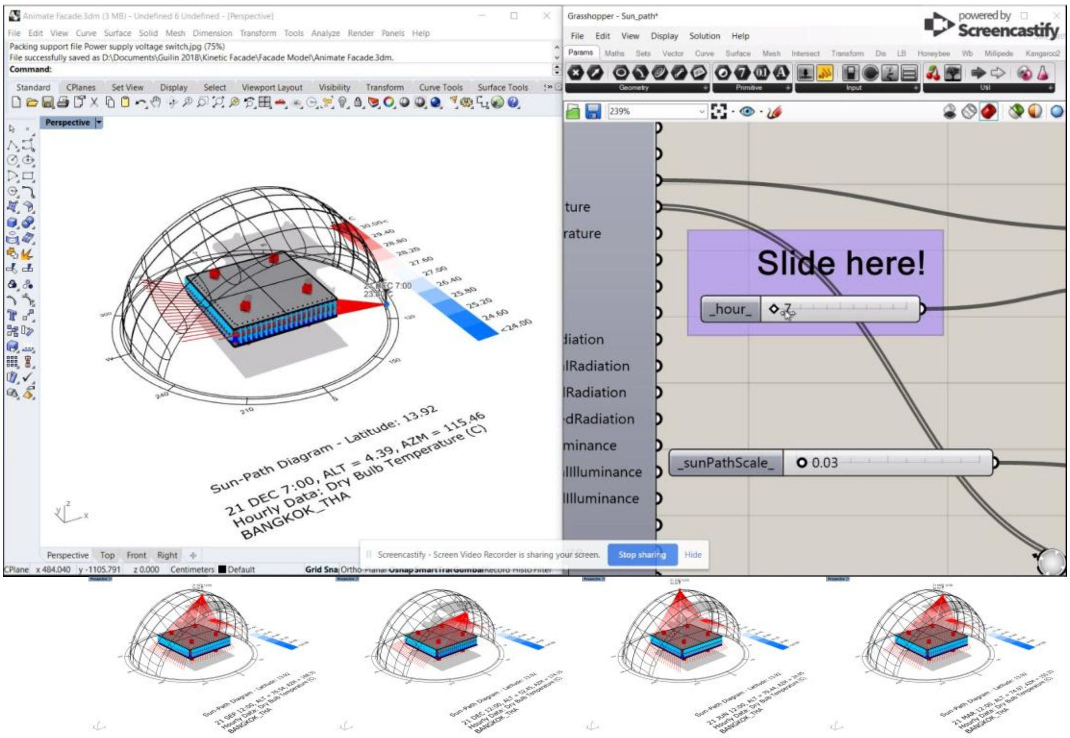

Figure 9 An animation showing fins movement according to sun path

The main purpose of this prototype is to test whether the idea of numerous fins for kinetic façade can be implemented. It also provides early feedback on design decisions. From the prototype, it is found that numerous fins for kinetic façade are difficult to implement for many reasons:

- installing one motor for every single fin is costly, even for a prototype,
- the wiring is complicated and it's easy to make mistakes,
- the Arduino diagram is difficult to be drawn correctly for an effective communication.

Even though it is technically possible to prototype the kinetic façade with numerous fins for an aesthetic purpose, a number of things are to be considered in real world applications. Having too many kinetic fins on a building (160 fins on each floor - 3,520 fins for the whole building) would rather give an undesirable outcome, mainly for economic reasons:

- the building will consume a lot of energy from the motors that drive the fins,
- installing one motor for every single fin will be costly at the end.

The bottom line is the company should reconsider their approach and change the project to something less expensive, such as animating part of the fins and not every fin on the building. Furthermore, the view point of the kinetic façade should be studied: where is the best place to observe this aesthetic sequence?

Apart from the prototype that shows an aesthetic sequence, in terms of solar control, the computer simulation shows that:

- the fins proposed by the company are all vertical ones, therefore not optimized, as the horizontal fins are more efficient for solar control for the West façade,
- the size of the aluminium fin is too narrow to give a visible effect on an aesthetic movement,
- when the shading is optimized, the view has to be compromised.

This is because, first, the fins are designed by the Aluminium profile company after the building is finished. Second, the company did not have an idea how to design effective kinetic fins for solar control. We can conclude that a kinetic façade should be designed by an expert in kinetic facade design for solar control. And the design should be integrated into the overall design of a building, not to be installed after the building is finished.

Finally, the prototype would rather serve for a demonstrative purpose. The company can show the kinetic façade technology to their clients. Or the teacher can use this prototype to show the students how an interactive façade works and how it responds to the sun position. More work can be done regarding programming of the kinetic façade: a simulation of the kinetic façade is shown on the Rhino-Grasshopper simulation but not yet programmed. The interaction between Rhino-Grasshopper and Arduino is programmable using Grasshopper's Firefly plugin. Apart from that, we can consider adding light sensors to the Arduino board. Thus the fins will become responsive to light sensors to maximize shading. Moreover, the fins can be programmed to be responsive to daily sun paths with a feedback loop using light sensors to maximize shading in case of a cloudy sky.

5. Conclusion

This prototype serves as a testing environment for the announced research question: "Is it possible to make a kinetic façade made of numerous adaptive aluminium fins?". With this prototype, the concept of kinetic façade with many fins has been proven. However, the work presented here is the first steps in solving a design problem, given by the Aluminum profile company. It is not the complete solution. Ideally, the question should be generalizable so that the solution can be used by others facing the same type of question. Generalization of the research requires sufficient recurring experiments, thus allows the researcher to make a conclusion using an inductive reasoning.

6. Acknowledgements

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