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Simulation on Building Envelope Design using Biomimicry Conceptual of Palm Leaf Pattern for Self Cleaning Maintenance

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ABSTRACT

Contemporary architectural designs acting to increase the aesthetic value of the building's overall perspective. The complexity of the maintenance works for the building envelope cleanliness becomes challenging in maintenance operations. Biomimicry – innovation inspired by nature, reveals an opportunity to simplify the cleaning process mentioned by infusing the self-cleaning characteristic of palm tree species on the design of building envelope. This research is intentionally to determine of the most ideal building envelope form that utilize the effect of the biomimicry conceptual as self-cleaning maintenance properties by finding the wind velocity to assess the dust flow behaviour. The basic architectural forms that commonly applied by the architects is used as a model to create the building forms in a way to find the physical self-cleaning characteristic by using the palm leaf pattern. By using the Autodesk Computational Fluid Dynamics (CFD) software, this tool is used to simulate the environmental situation and examine the efficiency of the self-cleaning function on different building models. The results are compared among the different models to identify the best building model that fully employ the self-cleaning function using the palm leaf pattern. The finding on self-cleaning properties of architectural forms is potentially developed the solution of sustainable building envelope design for a better functional and free maintenance.

1. Introduction

Building is created to attain the individual desires beside to assist their contentment, security and shelter to protect them from extreme mother nature. This structure component sets the building form and envelope typically build with strong shell as the outer element to ensure the building stability and functionality performance is satisfied. Furthermore, building envelope has exhibits its importance functions in protecting the occupants against all natures, climate changes and to secure the occupants from harmful. In the passage of time, the clients' and architects' desire eager to perform a better building design and it has seen as a part of corporate strategy and marketing to the property besides inventing the image of the clients and expend the tourism industry. Therefore, the

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variety of building architecture and aesthetic require an advance innovation in technology and construction to suit the futuristic building envelope and its components is likely to be developed hastily [1-2]. Thus, it is also creating the impact to the future building maintenance that might cause to complications in maintaining the structure [3] especially in dealing with life-cycle cost in a long-term cost efficiency [4-5].

The maintenance on building envelope has proven to be important element to prolong the life span of a building as the envelope is the key for sustainable energy development [6]. The building facade requires periodic maintenance although the roof is widely recognized as needing preventive maintenance and few owners understand that the vertical closure requires a similar commitment to preventive maintenance [7-8]. Complicated building envelope design raise concerns in challenging maintenance as the exquisite building forms makes its accessibility inconvenient [8] that cause to the difficulties in cleaning work on building envelope [8]. The approach of self-cleaning coating in concrete and stones research [9] thus bring the conceptual of the potential of self-cleaning building envelop in architecture. Self-cleaning maintenance method has the potential to ease up the maintenance works on extraordinary building envelope design and retains the beauty of it simultaneously.

Biomimicry concept is one of the potential approaches in this research to develop self-cleaning maintenance building envelope. Both biomimicry and biomimetics are pristine sciences that witness the materials in nature and then aim to create solutions for humans by mimicking these designs or by acquire inspiration from them [10-13]. In construction context, biomimicry exhibits a bright future for advance building envelope development in terms of sustainability.

Palm Trees, or scientifically known as Aceraceae are trees with humongous evergreen leaves in fan shape or long feather-liked shape and found mostly in areas under tropical or subtropical climate such as Malaysia. Palms are valuable resources as it contributes much in a nation's economic growth because it included major plantation crops such as coconut oil and palm oil [14]. Other than crops, the palms have considerable aesthetic shape which is an inspiration for architectural styles and building forms and patterns modification. The palms were also known to be self-cleaning trees and doesn't require any trimming, cleaning or cutting any parts from the trees [15-17]. However, it has not been established in biomimetic envelope strategy to suits every complicated aesthetic building forms, shapes and patterns. Therefore, this approach is intentionally to determine the most ideal building envelope design that can fully compatible with the self-cleaning characteristics of palm trees biomimicry conceptual by conducting simulation on building models that would consider all building forms, shapes and patterns. Specifically, it has been tested with two species which is licuala and Johannesteijsmannia after screening the characteristics, durability, self-cleaning feature and aesthetic. Licuala palm leaf has most high self-cleaning characteristic after Johannesteijsmannia even the it has thin leaf [31]. However, its clean surface has highlighted the shining and smooth exterior on its leaf has proven that licuala has carry a strong identity of self-cleaning biomimicry conceptual.

The approach for most ideal building envelope design using biomimicry self-cleaning maintenance conceptual is tested using Autodesk Computational Fluid Dynamic (CFD) software. Based on the study, licuala palm tree leaf inspired the researcher to build the biomimicry conceptual self-cleaning characteristic on building envelope design. Therefore, this article is purposely to determine the best building form that merge effectively with the palm tree pattern inspired by biomimicry self-cleaning maintenance conceptual.

2. Literature Review

Imitating and mimicking the forms of plants and animals is another method of translating nature behaviour, approaches and analogies in growth and evolution from decades ago [18-19]. Engineers discovered that functional biomimicry propose an alternative that could enhance the thermal performance of building facades and to lower the consumption of operational energy while retaining the thermal comfort of building occupants [20]. In the architecture context, biomimicry begins to be possible solutions and potential recommendation exploiting nature behavioural. For example, Figure 1 shows the design of Beijing National Stadium located in Beijing, China [12].

Fig. 1. Beijing National Stadium (left) and A Bird Nest (right) [12]

This stadium inspired by a bird nest structure. It was found that the adaptation of biomimicry imitated from the behaviour level which that the building façade openings allow its natural ventilation. The imitation of the openings of a bird nest that enable the natural ventilation as well [21] bring the sense of welcoming and the function suit to occasion of the building itself [22].

2.1 Maintenance Issues on Building Envelop

Retaining a building in a condition in which it unceasingly to attain its purpose and ensuring it presents a captivating exterior are also significant factors made possible through appropriate building maintenance method [3]. Building maintenance seems to be neglected much by the society these days. The building envelope maintenance is a part of the issues which most recent buildings were designed with various unique shape and form that results the difficulty and complexity in maintenance operation. Approximately 75–80% of the overall building costs occur during the occupancy and overall maintenance stage [2] for a building with a service life of 50 years [3,29]. The impact of the economic validated the significance of building maintenance [21,30]. Different components of building require different maintenance work procedure to ensure the respective component of the building function well enough to sustain the life span of the whole building [30]. As the building potential line of defence against environmental impacts which influences other sustainability factors, it is significant to make building envelope sustainable with suitable and correct maintenance work. [29-30].

The characteristic in adapting the surrounding condition naturally, building envelope can be integrated with biomimicry approach which will make the building envelope function like living organisms, and to satisfy current requirements to alter them adaptable to surrounding climate condition and capable to deliver all their needs for energy from the surrounding nature [21]. However, the maximisation of biomimetic approach effect on building envelope is heavily related to the building forms [19]. The sustainable building envelope design must consider all competing sustainable development factors to shape an exceedingly sustainable building envelope to attain the building sustainability goal [22]. Thus, biomimicry is the one of the potential methods for self-cleaning maintenance of the building envelope.

2.2 The Potential of Licuala Palm Leaves as Free Maintenance Conceptual

As much as Licuala Palm (Scientific Name: Licuala Grandis) or commonly known as Ruffled Fan Leaf Palm, Vanuatau Palm and Palas Payung originates from tropical rainforests of Southern Asia, New Guinea and Pacific Ocean Islands [23]. The licuala palm have solitary trunk up to 3m in height and 5 to 6cm in diameter. The leaf is circular in shape, undivided and regularly pleated leaf; approximately 22 inches or more in diameter with a notched edge, with the old dry leaves persisting [23]. A crown of 12 to 20 beautiful leaves attached on top of the thin, fibre covered trunk of the licuala palms. Each glossy, deep green frond is wedge-shaped and the frond stems (petioles) are long and have sharp, curved teeth at the base as shown in Figure 2.

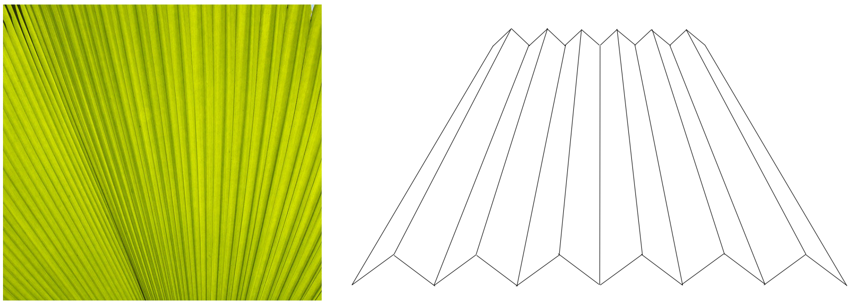


Fig. 2. Licuala Leaf Pattern has tilt pleated between 20° - 30° [15]

This pressed moulded in 20° - 30° tilt to form pleats on the leaf surface. There has two kind of surface samples will be made which is straight surface and curvy surface that shown in Figure 3. In addition, this similarity is slightly similar to a research which that discovered the building envelop can be designed in angles 30˚, 50˚, 70˚ and 90˚[24].

Fig. 3. Licuala Leaf Form in flat surface [15]

Fig. 4. Licuala Leaf Form in curvy surface [15]

The above figures show that licuala can formula in a flexible form. However, both forms have the same slope in pleated tilt [25]. The leaf bone called petioles functioned as to protect the organ of the leaf [26-27]. The number of veins or costae in the sections is consistently continuous in some species, but it's different to other species that form by segments of range folds [27]. Furthermore, this shining surface on the folded fan form helps this plant to be more free hand on its maintenance [26].

2.3 Basic Architectural Form and Function

Forms is a term that has multiple meanings that bring a strong appearance in architecture. In built environment context, form represents the formal structure of an architect's masterpiece which is coordination and arrangement of elements and parts of composition to create a coherent image [28]. The fundamental of creating the forms is stating from the shapes, which is the characteristic outline or surface configuration of a specific form and the basic shapes that are familiar by the world are square, triangles and circles as shown in the Figure 5 below [28].

Fig. 5. Fundamental Architectural Shapes [28]

The above shape has to develop by adding volume to create space in building architectural which that suit with its function. Those basic form starting with basic form resembling in Figure 6, however it has to be transformed to show the creativity, strong conceptual and aesthetic on the building.

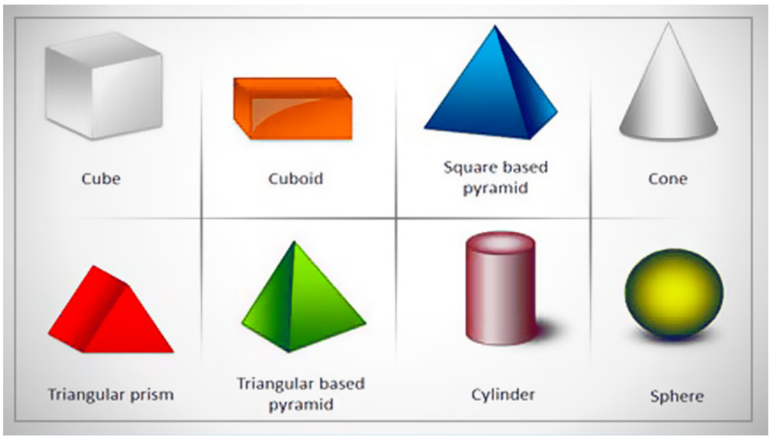


Fig. 6. The basic form in architecture [28]

The basic forms above consist of few surfaces that is flat, curve and slant [28]. The transformation on basic form has a power in increasing the aesthetic values in architecture. However, the difficulties of maintenance actually have begun at this stage [33] whereby the critical issues on maintenance storage, access, plants and machineries, operation, risk and challenges remain unsolved till the management faced the reality in maintaining the stunning architecture [29-31].

2.4 The Potential of Computational Fluid Dynamics (CFD) in Determine the Self-Cleaning Characteristic

Computational Fluid Dynamics (CFD) is a method to analyse and answers to the fluid flows problems with fluid mechanics that incorporate numerical analysis and data structures, is like substitute the partial differential equations of fluid flow with numerical figures, and advancing the figures in time or space to acquire a final numerical description of the complete flow field of interest [34,36]. The fundamental governing equations of fluid dynamics is the backbone of computational fluid dynamics (CFD). There are three fundamental physic principles which all fluid dynamic based on are mass is conserved, Newton's second law (F=ma) and energy is conserved [13]. The equipment which enable the practical growth of CFD is digital computer because CFD solution requires repetitive manipulation of millions of numbers [35]. In past history, CFD has been studied and it was found that it can be a tool for evaluating various aspects such as heat and mass transfer between indoor environment and building envelope, wind flow and external environment related processes around building, wind-driven rain (WDR) on building façade, pollutant dispersion around buildings, exterior building surface heat transfer, natural ventilation of buildings and wind loading of buildings [36].

3. Research Methodology

The approach of this research is deliberating the simulation on fluid aerodynamic tests is tested on the building form from the basic form models [37,44]. A set of building models is created using three sample on basic forms [24,28]. The test considering the similarity on exposed area on forms' surface that attached with basic architectural forms and texture from licuala palm tree leaf inspired biomimicry conceptual envelope patterns were designed and created. The Figure 7 shows the character of the models.

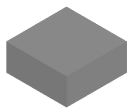
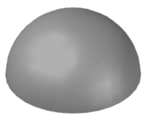
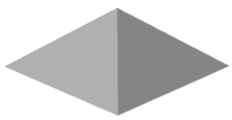
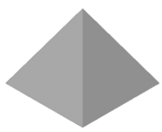
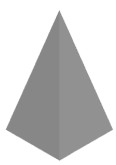
Type of Forms	Width (m)	Length (m)	Height (m)
Cube 	45	45	20
Hemisphere 	45(diameter)	45	22.5
Pyramid With 30° Slope 	45	45	19
Pyramid With 50° Slope 	45	45	38
Pyramid With 70° Slope 	45	45	88

Fig. 7. Examples of Licuala Palm Tree Leaf Biomimicry Conceptual Patterns

Each of the building models have different shape of envelope surface, therefore unique biomimicry conceptual envelope patterns were designed specially to suit the respective envelope of those building model. A suitable test using wind turbine is relevant to determine the velocity of the wind in variety of form [44] that believe as it will help to clean the surface of the form. However, this exercise can be transformed into Computational Aid Design (CAD) software [43] to find the aerodynamic and wind velocity for each form, which in this research AutoCAD software by Autodesk was used. Solid models in form of cube, hemisphere, pyramid with 30° slope sides, pyramid with 50° slope sides and pyramid with 70° slope sides was constructed. The pyramid models designed with the slope according to the nature of Licuala leaves' characteristic [24] while the other forms are created from the basic architectural forms [28]. However, the area of each base has uniformly size to create the equal area. These solid models were based on minimum standard simulation size of commercial building in world-wide architecture [38]. This standard form on external form which consider as building envelope adapting the biomimicry conceptual using Licuala Palm Tree Leaf Pattern and texture as shown in Figure 8.

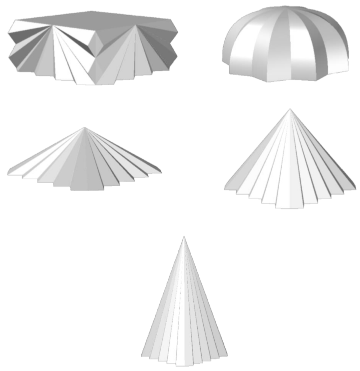


Fig. 8. Licuala Palm Tree Leaf Biomimicry Conceptual Patterns and texture on building models that is Cube, Hemisphere, Pyramid With 30° Slope, Pyramid With 50° Slope and Pyramid With 70° Slope

This form has to exercise the nature of the Licuala palm leaf pattern which has a pleated surface and shining [27]. Then, the wind loading model in Figure 9 for the simulation test is created.

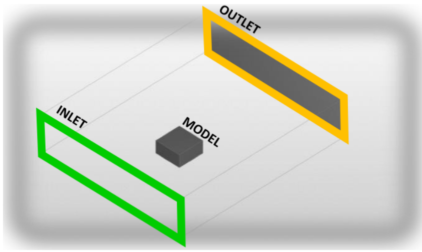


Fig. 9. Wind Loading Model

Each solid building model will be placed at the specific location which is distance of 2 times width of model from the inlet face and distance of 2 times width of model from the side faces inside the wind loading model for each respective simulation test. The variables such as material properties, condition of scenario environment, boundary condition, mesh sizing and solver settings has been inputted on the simulation.

The differences of the mass flow rate and volume flow rate for both basic architectural models and biomimicry conceptual solid models which that subtracted the mass flow rate or volume flow rate of basic architectural solid model with the mass flow rate or volume flow rate of biomimicry conceptual solid model. It is to calculate the efficiency percentage of self-cleaning characteristic. A standard k-ß turbulence model was used in simulation test by starting the turbulent incompressible flow and 750 iterations was set to run.

The data table was tabulated by using Microsoft Excel software to record all the readings of the result quantities at the outlet. The result quantities at the outlet recorded were area of the plane, density, mass flow rate, pressure, pressure force, viscosity, volume flow rate, vx-velocity, vy-velocity and vz-velocity. Other than that, velocity magnitude result planes in xy-axis and xz-axis was created to show the velocity of wind flow at different area around the solid models.

The differences of the mass flow rate and volume flow rate for both basic architectural models and biomimicry conceptual solid models in subtracting the mass flow rate and volume flow rate of basic architectural solid model with the mass flow rate and volume flow rate of biomimicry conceptual solid model. This method is used to calculate the efficiency percentage of self-cleaning characteristic using Licuala pattern on the building envelope. The efficiency percentage was calculated from the simulation test represents the improvement of self-cleaning ability from the basic solid building models to the biomimicry conceptual solid building models. The efficiency percentage was calculated by using the formula shown below.

$$\text{Efficiency Percentage} = \frac{\text{Differences of Mass Flow Rate}}{\text{Mass Flow Rate of Basic Building Model}}$$

$$\text{Efficiency Percentage} = \frac{\text{Differences of Volume Flow Rate}}{\text{Volume Flow Rate of Basic Building Model}}$$

The comparison of efficiency percentage on the model shows the higher efficiency percentage that will be the most ideal building envelope design as the palm tree leaf inspired biomimicry self-cleaning conceptual. Other than that, the models with slope sides such as the pyramids will be comparing to determine the relationship between degree of slope and the effectiveness of biomimicry conceptual self-cleaning characteristic.

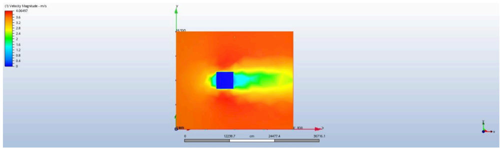
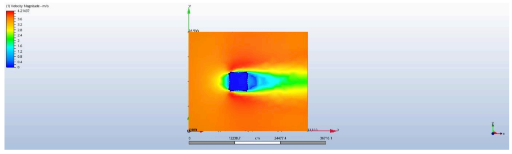
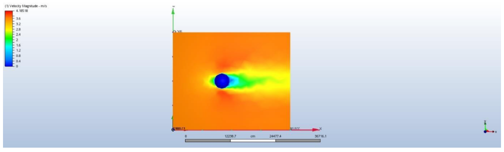
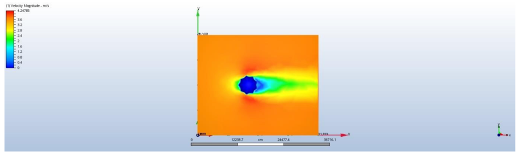
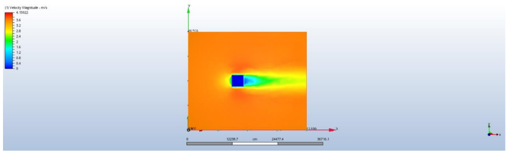
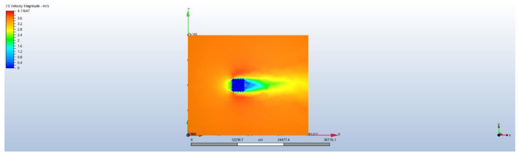
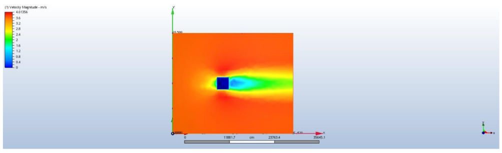
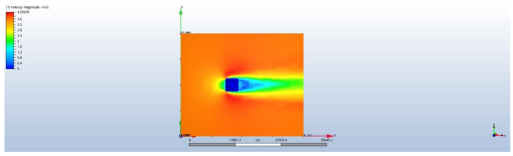
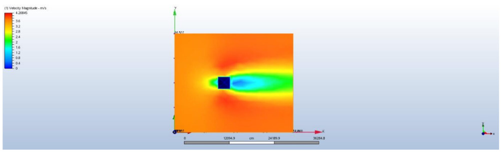
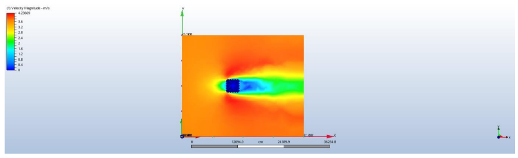
4. Result

All the data findings from the simulation test are produced by the Autodesk Computational Fluid Dynamics (CFD) software’s solver settings and calculation. A total of 10 models have been tested under the same variables input in the software, and each of the results is recorded.

4.1 Wind Velocity Magnitude XY-Axis Plane Analysis Differences of Volume Flow Rate Volume Flow Rate of Basic Building Model

Wind velocity is an important component in this study in developing free maintenance surface. The form of the building could influence the impact on flow and velocity of the wind. Table 1 shows the result of *wind velocity magnitude xy-axis plane analysis between plane surface on the basic form in comparison with the same form by adapting biomimicry conceptual.*

Table 1
The comparison of *Wind Velocity Magnitude XY-Axis* between XY-Axis Wind Velocity Magnitude Plane on Basic Form Building Model and XY-Axis Wind Velocity Magnitude Plane Using Biomimicry Conceptual

Type of Basic Form	**XY-Axis Wind Velocity Magnitude Plane of Basic Form Building Model**	**XY-Axis Wind Velocity Magnitude Plane Using Biomimicry Conceptual on Basic Form Building Model**
CUBE		
HEMISPHERE		
PYRAMID WITH 30° SLOPE		
PYRAMID WITH 50° SLOPE		
PYRAMID WITH 70° SLOPE		

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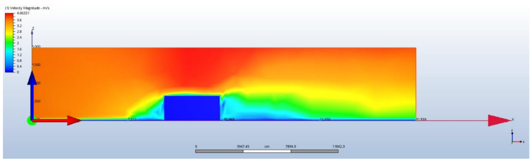
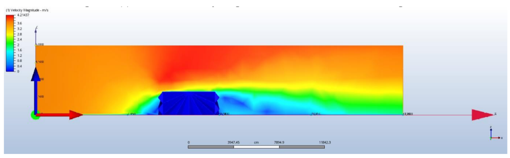
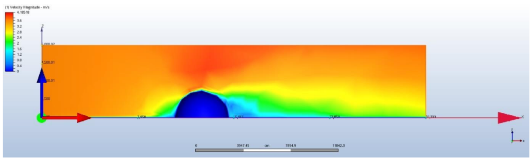
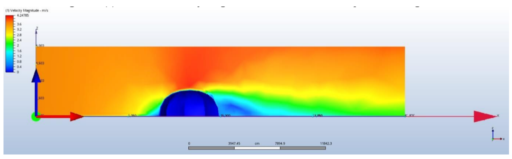
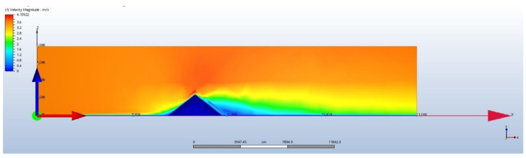
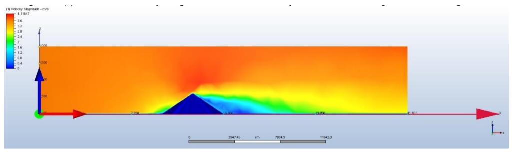
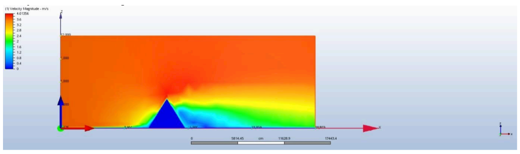
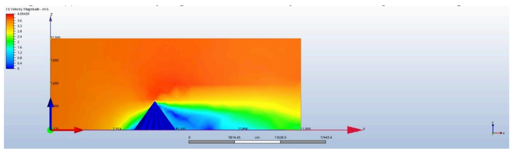
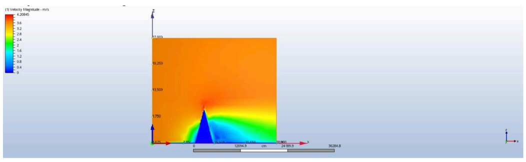
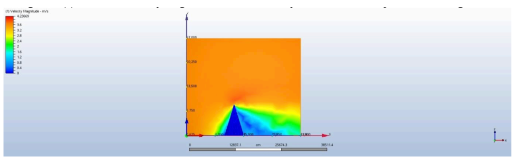
The result from CFD shows that the XY-axis wind velocity magnitude at the behind of biomimicry conceptual building models are lower compare to the basic plane building models. However, this test does not deliberate the orientation of the models that might influence a different result from above findings. The lowest wind velocity can be seen from biomimicry conceptual on cubic model followed by biomimicry conceptual on pyramid with 70° slope model. This prove that biomimicry conceptual using Licuala pattern and texture is capable to protect the building from any damages cause by high range of wind velocity eg. storm [39].

4.2 Wind Velocity Magnitude XZ-Axis Plane Analysis

This result is to show the pattern of the wind flow from the xz-axis plane analysis using CFD software. It is important to show the range of wind velocity from the vertical sight. Table 2 shows that comparison of Wind Velocity Magnitude XZ-Axis between XY-Axis Wind Velocity Magnitude Plane on Basic Form Building Model and XZ-Axis Wind Velocity Magnitude Plane Using Biomimicry Conceptual.

Table 2
The comparison of *Wind Velocity Magnitude XZ-Axis* between XY-Axis Wind Velocity Magnitude Plane on Basic Form Building Model and XZ-Axis Wind Velocity Magnitude Plane Using Biomimicry Conceptual

Type of Basic Form	**XZ-Axis Wind Velocity Magnitude Plane of Basic Form Building Model**	**XZ-Axis Wind Velocity Magnitude Plane Using Biomimicry Conceptual on Basic Form Building Model**
CUBE		
HEMISPHERE		
PYRAMID WITH 30° SLOPE		
PYRAMID WITH 50° SLOPE		
PYRAMID WITH 70° SLOPE		

The pattern of wind velocity is proven by referring to the table above. The wind velocity become lower on behind of the biomimicry conceptual building model is lower as compared to the basic building model on each model. Therefore, the Licuala pattern demonstrate that the wind speed can be reduced using the biomimicry conceptual on building envelope besides of increasing the height of the building [39,40].

4.3 Simulation Test Result Quantities Analysis

Table 3 shows that the simulation test result in quantities analysis. This test representing the character of the wind that influence by the conceptual of the building using basic plane form and biomimicry theory. The data shows on wind density, mass flow rate, pressure, pressure force, viscosity, volume flow rate, vx-velocity, vy-velocity and vz-velocity.

Table 3
The comparison of simulation result between basic form model and biomimicry conceptual model

BUILDING FORM	Area (m2)	Density (kg/m3	Mass Flow Rate (kg/s)	Pressure (Pa)	Pressure Force (Newton)	Volume Flow Rate (m3/s)	Vx-Velocity (m/s)	Vy-Velocity (m/s)	Vz-Velocity (m/s)
Cube (Basic Form)	15900	1.20473	67874.1	-0.0017839	-22.2872	56339.4	3.54336	0.00041125	-0.0023719
Cube (Biomimicry Conceptual)	15900	1.20473	68745.9	-0.0047645	-62.7216	57063.1	3.58888	0.00046207	0.00022522
Hemisphere (Basic Form)	15900	1.20473	68397.2	-5.857705	1.98242	56773.6	3.57067	-7.397505	9.547505
Hemisphere (Biomimicry Form)	15900	1.20473	68551.5	-0.0017878	-26.4886	56901.7	3.57872	0.00105198	-0.0023516
Pyramid With 30° Slope Sides (Basic Form)	15900	1.20473	68477.1	-0.0040219	-63.6263	56480	3.57485	0.00026287	-0.0047189
Pyramid With 30° Slope Sides (Biomimcry Conceptual)	15900	1.20473	68752.9	2.87505	0.654072	57068.9	3.58924	5.687505	0.0004991
Pyramid With 50° Slope Sides (Basic)	15900	1.20473	137226	-0.0031465	-92.9096	113905	3.58193	-8.69755	-0.0088118
Pyramid With 50° Slope Sides (Biomimicry Conceptual)	15900	1.20473	137919	-0.0019598	-54.0461	114481	3.60003	-0.0002108	-0.0060752
Pyramid With 70° Slope Sides (Basic)	15900	1.20473	308929	-0.0035338	-241.605	256429	3.58191	7.767505	-0.0066287
Pyramid With 70° Slope Sides (Biomimicry Conceptual)	15900	1.20473	310768	-0.0036529	-231.298	257956	3.60525	-0.0001271	-0.0141194

Based from the above data, the wind mass flow increased on cubic form using biomimicry conceptual with 68745.9 kg/s while the lowest is pyramid form in 50° slope with 137226kg/s. However, the wind pressure brings the distinctive result which is the lowest pressure is hemisphere basic plane form with -5.857705Pa compared to Pyramid With 30° Slope using biomimcry conceptual with 2.87505Pa. The high wind pressure will help the self-cleaning potential on its surface as like Licuala characteristic. This is because the pressure force of this concept balance with 0.654072N. Nevertheless, the lowest pressure force is the form of basic plane pyramid with 70° slope. This might be the weakest form in self-cleaning characteristic for design maintenance performance.

4.4 Matrix Tabulation Analysis

In order to ensure the self-cleaning characteristic is created on these models, the debris has created on the surface to test the performance of free maintenance atmosphere. In this result, Table 4 show the data on mass flow rate analysis.

Table 4
Summary Table of Mass Flow Rate

Building Forms	Mass Flow Rate (kg/s)	Difference (kg/s)	Self-Cleaning Efficiency Percentage (%)
Cube (Basic Form)	67874.1		
Cube (Biomimicry Conceptual)	68745.9	871.8	1.28
Hemisphere (Basic Form)	68397.2		
Hemisphere (Biomimicry Form)	68551.5	154.3	0.23
Pyramid With 30° Slope Sides (Basic Form)	68477.1		
Pyramid With 30° Slope Sides (Biomimicry Conceptual)	68752.9	275.8	0.40
Pyramid With 50° Slope Sides (Basic)	137226		
Pyramid With 50° Slope Sides (Biomimicry Conceptual)	137919	693	0.51
Pyramid With 70° Slope Sides (Basic)	308929		
Pyramid With 70° Slope Sides (Biomimicry Conceptual)	310768	1839	0.60

Based on Table 4, the efficiency percentage of each building forms category has been calculated by using the formula mentioned in the previous chapter of methodology. The mass flow rate efficiency percentage for each respective building forms of cube, hemisphere, pyramid with 30° slope sides, pyramid with 50° slope sides and pyramid with 70° slope sides are 1.28%, 0.23%, 0.40%, 0.51% and 0.60%. By comparing the efficiency percentage of every building form, the cube form has the highest efficiency percentage among all the other form which means the increment of mass of dust particles flow out from the wind loading model from basic architectural form building model design to biomimicry conceptual building model design is the largest as compared to the other building form category. With the highest efficiency percentage of 1.28%, cube form becomes the most ideal building form that could adopt the palm tree leaf inspired biomimicry conceptual envelope design for self-cleaning maintenance. To test the volume of the wind, Table 5 present the data of volume flow rate summary analysis.

Based on Table 5, the efficiency percentage of each building forms category has been calculated by using the formula mentioned in the previous chapter of methodology. The volume flow rate efficiency percentage for each respective building forms of cube, hemisphere, pyramid with 30° slope sides, pyramid with 50° slope sides and pyramid with 70° slope sides are 1.28%, 0.23%, 0.40%, 0.51% and 0.60%. %. By comparing the efficiency percentage of every building form, the cube form has the highest efficiency percentage among all the other form which means the increment of volume of dust particles flow out from the wind loading model from basic architectural form building model design to biomimicry conceptual building model design is the largest as compared to the other building form category.

Table 5
Summary Table of Volume Flow Rate

Building Forms	Volume Flow Rate (m3/s)	Difference (m3/s)	Self-Cleaning Efficiency Percentage (%)
Cube (Basic Form)	56339.4		
Cube (Biomimicry Conceptual)	57063.1	723.7	1.28
Hemisphere (Basic Form)	56773.6		
Hemisphere (Biomimicry Form)	56901.7	128.1	0.23
Pyramid With 30° Slope Sides (Basic Form)	56840		
Pyramid With 30° Slope Sides (Biomimcry Conceptual)	57068.9	228.9	0.40
Pyramid With 50° Slope Sides (Basic Form)	113905		
Pyramid With 50° Slope Sides (Biomimicry Conceptual)	114481	576	0.51
Pyramid With 70° Slope Sides (Basic Form)	256429		
Pyramid With 70° Slope Sides (Biomimicry Conceptual Basic)	257956	1527	0.60

With the highest efficiency percentage of 1.28%, cube form becomes the most ideal building form that could adopt the palm tree leaf inspired biomimicry conceptual envelope design for self-cleaning maintenance. For slope sides building model such as pyramids, the data analysis showed that the degree of slope is directly proportional to self-cleaning efficiency percentage. The relationship between the degree of slope and self-cleaning efficiency percentage is described in the Figure 10 below:

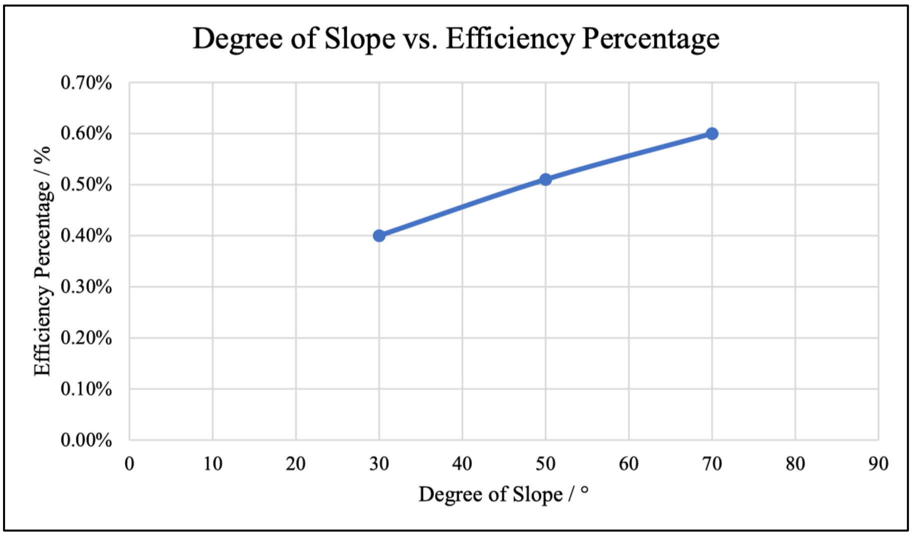


Fig. 10. Graph of Degree of Slope versus Efficiency Percentage

Based on Figure 11, higher wind speed results in higher Dust Concentration Index (DCI) [41]. According to the data analysis in this research, the wind velocity surrounds biomimicry conceptual building model is lower than basic building models resulting the dust concentration deposited on the building envelope lower as well.

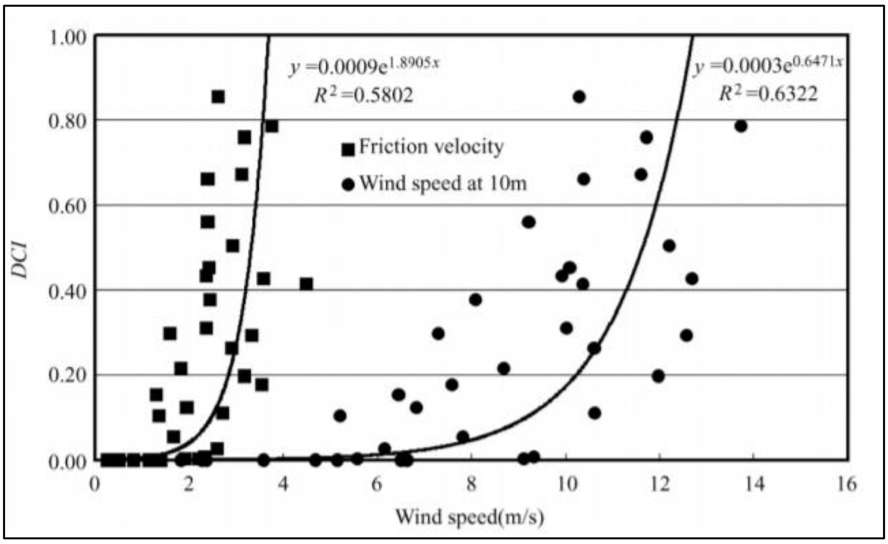


Fig. 11. Relations Between Dust Concentration Index (DCI) And Wind Speed and Friction Velocity [15]

Based on Figure 19, higher wind speed results in higher Dust Concentration Index (DCI) [41]. According to the data analysis in this research, the wind velocity surrounds biomimicry conceptual building model is lower than basic building models resulting the dust concentration deposited on the building envelope lower as well.

5. Conclusion

The result from this exercise can prove that biomimicry conceptual can be developed into self-cleaning and free maintenance on designing the building envelope. The virtual environmental simulation test presents that cube form is the most ideal building form by adapting the licuala leaf pattern on the surface which represent the building envelope and it is inspired biomimicry conceptual self-cleaning design.

This analysis has provided guidance on the application and test on self-cleaning building envelope design in applying biomimicry conceptual for advance architecture in the construction industry. With employing Licuala self-cleaning characteristics on envelope design as example, this investigation has demonstrated the potential of biomimicry on offering sustainability for envelope design to maintain the functionality of envelope in building context. The demand of sustainable building designs is widespread throughout the human civilisation. Exposure of the diversity of self-cleaning maintenance strategies that permeate the nature world, there are still abundant of opportunities to translate those strategies to human's technology on the cleanliness maintenance of building envelope. However, this research can be expended to explore on orientation of the models that might give the potential research area in the future.

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