Reasearch on Physical Wind Tunnel and Dynamic Model Based Building Morphology Generation Method

YUQIONG LIN¹, JINGYUN ZHENG², JIAWEI YAO³ and PHILIP F. YUAN⁴
¹,²,³,⁴College of Architecture and Urban Planning, Tongji University, Shanghai, China
¹,²,³,⁴{1630237|1530298|jiawei.yao|philipyuan007}@tongji.edu.cn

Abstract. The change of the building morphology directly affects the surrounding environment, while the evaluation of these environment data becomes the main basis for the genetic iterations of the building morphology. Indeed, due to the complexity of the outdoor natural ventilation, multiple factors in the site could be the main reasons for the change of air flow. Thus, the architect is suggested to take the wind environment as the main morphology generation factor in the early stage of the building design. Based on the research results of 2017 DigitalFUTURE Wind Tunnel Visualization Workshop, a novel self-form-finding method in design infancy has been proposed. This method uses Arduino to carry out the dynamic design of the building model, which can not only connect the sensor to monitor the wind environment data, but also contribute the building model to correlate with the wind environment data in real time. The integration of the Arduino platform and the physical wind tunnel can create the possibility of continuous and real-time physical changes, data collection and wind environment simulation, using quantitative environmental factors to control building morphology, and finally achieve the harmony among the building, environment and human.

Keywords. Physical wind tunnel; dynamic model; building morphology generation; environmental performance design; wind environment visualization.

1. Introduction

The environmental elements, including the wind, exist as the form and function of a field between the building and the site. Such internal rules and connections determine the objects on the building and the site. Environmental performance drives the generation of architectural forms, using buildings that can quantify the environmental aspects of the building, creating a more meaningful diversity of architectural forms. Thus, the performance of the building environment includes environmental elements such as the wind, light, sound and heat. There are plenty of architects are already making great effort to reflect the simulation result of the building physical environment in the form of the initial design of the building.
The physical environment discussed in this paper is mainly about the outdoor ventilation. Due to the complexity of the wind around the building, a number of factors in the site environment can be the main reason for the changes of the wind field (Yuan et al., 2016). It is necessary for architects to take the environmental element of wind as the main basis of generation in the initial design.

From the Primitive Hut, people use design methods to fit the building’s construction to the environment. With the development of digital technology by leaps and bounds, physical and environmental data around and within buildings are often simulated and evaluated as a series of driving parameters for building performance. At the same time, these simulated data and diagrams provide an intuitive representation of the internal connections between architecture and the environment, and guide the optimization of the building’s subsequent design (Huang et al., 2015). Environmental Performance Diagram allows architects to maximize the use of external environment to generate a responsive building forms or dynamic skin that adapt to the natural system. Here, the architectural form becomes the interface that controls the surrounding natural environment and the interior architectural space. The sources of these forms are not accidental and subjective, but rather rational parameterized controls based on environmental data (Yuan, 2016). The change of building form directly affects the generation of various environmental data, and the evaluation of data has become the main basis for iterative inheritance of building form (Oxman, 2008).

In previous research, Computational Fluid Dynamics (CFD) software and physical wind tunnel are applied for characterizing the wind environment. In most cases, CFD software is used in the later stage of architectural design evaluation. Similarly, wind tunnels are also widely used in the post-evaluation stage of architectural design, or in the fields of aviation, bridges, automobiles and etc. As a simulation tool of the wind environment, the greatest strength of the physical wind tunnel is to visualize the wind flow with more reliable simulation result. Using the real air as the medium, the results of wind tunnel simulation are almost real-time, and do not require lots of parameter settings and knowledge of grids, so as to establish a platform for architects to simulate the wind environment more quickly and conveniently (Zheng et al., 2017). Wind tunnel simulation results can be visualized in variety ways, such as smoke visualization, which can clearly and intuitively record the dynamic air flow and the formation of wind fields around buildings (Alexander et al., 1997). In addition, the simulation data of physical wind tunnel can be extracted through the transformation of the electrical signal of the sensor.

However, the limitation of the application of physical wind tunnel to generate building form is also obvious. Although the physical wind tunnel can quickly and easily obtain the pre-designed wind environment data, which can quickly optimize the design, the model of the modified design is still unable to update instantly in the wind tunnel. It requires a large amount of manpower and financial resources to make the physical model continuously, which plunged the optimization of morphology into a cycle requiring artificial continuous operation. During the process, with the visualization of the wind flow simulation results surround the physical model, after the manual evaluation, the architects need to adjust
or re-create the building model based on the optimized design, to simulate in the wind tunnel again. It’s clear that the optimization is a process of artificial iteration and evaluation, which is too dependent on the designer’s experience in judging the environmental performance. Moreover, the model reconstruction due to non-digital iteration of the morphology generation is inefficient.

So far, the design of the return from physical wind tunnel analysis is still not able to really jump out of the “post-evaluation” mode. To improve the previous generation method based on the physical wind tunnel, the mechanical dynamic model is proposed in the morphology generate process, enabling the design model to adjust by itself in real-time according to the wind speed obtained through the sensors, which can solve the main problem existing of the previous generation method in this paper (Menicovich et al., 2002).

2. Morphology Generation Tools

2.1. MINIATURE WIND TUNNEL 2.0

The wind tunnel used in the experiment is a miniature wind tunnel 2.0 as shown in Figure 1, which is improved on the basis of wind tunnels produced in previous studies. Its reliability has been verified in previous studies (Zheng et al., 2017). The total length of the wind tunnel is 3 meters. It is an open-source uniform wind tunnel. Miniature wind tunnel can be divided into five detachable parts: (1) Stable section: the honeycomb and damping network inside can subdivide and comb the unstable inlet air, to obtain a smaller uniform turbulence; (2) Contraction cone: to accelerate the air flow and make it into a stable laminar wind; (3) Text section: perform the wind environment simulation test with a stable wind environment; (4) Diffuser: mainly to avoid the return of the air flow when encounter obstacles; and (5) Fan section: select the suction axial fan with a fairing, which can be connected to the fan inverter wind speed control, to obtain a relatively stable wind speed in the range of 0~10m/s. Miniature wind tunnel was assembled by the laser cutting glue plywood and plexiglass plate and can be refit according to the experimental requirements, so as to meet various measurement methods and research purposes. In this experiment, the fuming section was added on the basis of the original miniature wind tunnel, and the tobacco was heated by the heating wire to generate smoke with a certain distance, so that the air can be visually described (Ramkissoon, 2014; Philip, 2012). In the meanwhile, the bottom board of the test section was optimized and modified, reserving a suitable position for the measuring point of the sensors and the scope of the mechanical dynamic models’ movement, with the relevant sealing process.
2.2. WIND SENSOR

The sensor of Rev. P is selected in the experiment as the main sensor, which is thermo-sensitive wind speed sensor that provides more continuity with respect to pressure converted air velocity values in real time (Moya, 2015). Therefore, it also can transmit the electrical signal of the data to the Arduino board for further analysing in computer. The sensors are arranged in a matrix around the main building model in the wind tunnel, collecting a 1.5-meter pedestrian height wind speed value for evaluating the pedestrian level wind comfort (Salim, 2012). The number of sensors connected to each building model is limited by the Analog pin of Arduino board, while the Arduino MEGA board can connect up to seven sensors. However, in view of the stability, the study connects each building model with the five sensors around, to evaluate the pedestrian level wind comfort of the wind speed value collected.

2.3. ARDUINO PLATFORM

This method uses Arduino platform, an open source platform to carry out the dynamic design of the building model (Figure 2). Because it can not only connect the sensors to read the wind environment data, but also make the building models correlated with the wind environment data in real time. The integration of the Arduino platform and the physical wind tunnel creates the possibility of continuous and real-time physical changes, data collection and wind environment simulation, using quantitative environmental factors to control building morphology, and finally achieve the harmony among the building, environment and human.
2.4. MECHANICAL DYNAMIC MODEL

The mechanical transmission of the dynamic models brings a variety of possibilities to the building form. The rotation of the servos can be derived from different forms of movement of the building, while the rotation of the gear can drive shaft and other parts to complete the body model changes. The basic changes mainly consist of rotation, translation, stretching and shrinking. During 2017 DigitalFUTURE Wind Tunnel Visualization Workshop, design concept of rotation was chosen for model movement to achieve the self-form-finding process. Various form rotation status could be observed, while the typical angle with 30°, 60°, 90°, 120°, 150° and 180° have been displayed in Figure 3.

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Figure 3. Form generation diagram based on rotation.
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Dynamic building models’ production need to consider the penetration of the wind and the integrity of the volume and other issues. Therefore, the experimental building models are composed of the laser-cut 4 mm plexiglass plates superimposed, the largest border size of the volume is 65 * 65 * 200 mm, using a 65 * 65 mm rectangle as a standard layer prototype, and totally 50 layers. Among them, there are three active rotating plates, and the rest are passive rotating plates.
As shown in Figure 4, the three active rotating plates of the model are controlled by three different servos, which drives the three rotating shafts that are nested together to rotate through the servos’ transmission. The three axes of rotation are made of hollow ABS tubes, which respectively transmit the rotation of the corresponding servos to the corresponding active rotary plate. There are four elastic strings inside each model throughout, enabling the active rotating plates to drive the passive rotating plates to rotate while immobilizing two sides of the strings. In result, keep the rotation continuity of the entire model. Compared with elastic skin such as latex film, the tension of elastic string is moderate, therefore it can pull each passive rotating plate to rotate without affecting the rotation of the servos.

Figure 4. Dynamic model explosion diagram.
2.5. HORIZONTAL SLIDER

Due to the same procedural logic and wind environment, the morphology generated by the monomer model is unique. The research explores the morphology generation of three movable models in response to each other. The main part of the buildings is placed in the wind tunnel, while the mechanical transmission and the track below are located outside (Figure 5). Therefore, the whole device is fixed on the horizontal sliders. With the control of three horizontal sliders by pushing and pulling, the relative position of the buildings can be adjusted. In this condition, the various arrangements of the buildings lead to different wind environments data, resulting in different physical morphology.

![Image](image.jpg)

Figure 5. The dynamic building models and the visualized wind in wind tunnel.

3. Generation Logic and Workflow

Modern research on the dynamic architecture of self-forming changes still stays in the stage of concepts and installations. In this study, the buildings will not be changed in real time due to changes in the external environment. Because it is difficult to evaluate the best morphology corresponding to certain wind environment. The generation logic applied in this paper is similar to Galapagos in Grasshopper, collecting different building forms’ data and the corresponding environmental data brought by the building forms, comparing the average of the environmental data collected for a certain period of time with the comfort value, so as to screen out the optimal value, and then return to the building form which produces the optimal value through the list (Figure 6).

This research takes the 2017 DigitalFUTURE Wind Tunnel Visualization Workshop as a case study. Firstly, the Arduino controls the servo via calling program by its own servo library. The servo can rotate freely from 0-180°, so 0° is considered as its starting point. In each time of the rotation, Arduino records
the current status of the servo by recording its angle. The program is set to rotate the servo once every 1 second. The Arduino records the current angles of the three servos and the environmental data collected by five sensors at a time. The movement angle of each time can be set according to the requirements. The workshop choose to rotate the three servos by 1°, 5° and 10° respectively.

Then, setting the initial wind speed of wind tunnel, which in this case is 1.5m/s. After each rotation of the servo, the collected five wind speed data will be averaged, and the result will be compared with the comfortable wind speed (1m/s in this case) to obtain the absolute value of the difference.

Finally, after repeating 20 rotations and corresponding data collecting, the program automatically selects the data set with the lowest absolute value and find out the angle of the servo corresponding to the data set. Finally, the servos are returned to their corresponding status.

4. Experimental Results

By moving the push-pull sliders during each 10-second when models remain steady, a new different arrangement of these three building models will be generated. In this condition, according to self-form-finding strategy, these buildings will rotate, and the corresponding surrounding wind data will also be collected for finding the optimized building morphology. Once the surrounding mean wind has been calculated, it will compare to the default comfort wind speed value at pedestrian level. For example, 1m/s has been set as comfort wind speed in this study (Table 1). On the other hand, Figure 7 shows the optimal solution of the respective building forms in different arrangement.
5. Conclusion

The method presented here integrates the physical wind tunnel and dynamic model through Arduino platform, which can optimize the morphology generation in design infancy. It has a variety of design possibilities: Firstly, the standard layer prototype can be designed more freely, while the adjustment of the elastic strings’ position and the change of the center axis relative to the standard layer directly change the form of building model; In addition, the movement mode of the models can also be diversely designed, for instance, through the translation and other movement modes, which controls the dynamic change of the models arrangement. Moreover, the number of active rotating plates or servos can be adjusted to create the changeable morphology.

Based on the physical wind tunnel and dynamic building models, various problems of previous generation method based on the wind environment may have been solved, for example, avoiding repetitive manual labor brought by re-creation of the models. What’s more, with the models adjust by itself in real-time according to the wind speed, it enables the design jump out of the "post-evaluation" mode, which has great potential for derivation and design. Therefore, it creates a tight coupling between “performance evaluation” and “design optimization”, the optimization speed of the design has been a qualitative leap, and the instantaneous environmental performance-driving morphology generation has been realized. The architectural form will no longer be confined to mere aesthetics or space experience, but also to rational analysis and judgment, so as to make the architectural design more practical-significant and valuable.

When optimizing the generation logic, there is still some possibilities to
improve the workflow. In the final step of screening the optimal form, algorithm optimization may be necessary and significant. Currently, the optimal value is selected after rotations, however, the number of rotations is limited, and each rotation is based on a fixed angle, which results in a more random and limited number of alternative solutions for screening. With the advent of the intelligent era, the optimization of the algorithm may be the direction for the future improvement of this method. With AI’s application, using reinforcement learning, the algorithm may predict the optimal solution on its own after a large number of samples’ study, rather than selecting the optimal from the finite samples, so as to realize intelligent self-form-finding.

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