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A "Dynamic Form-Finding" Approach to Environmental-Performance Building Design

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Abstract

Newly-designed high-rise buildings, both in China and abroad, have demonstrated new innovations from the creative concept to the creative method. from the creative concept to the creative method. At the same time, digital technology has enabled more design freedom in the vertical dimension. "Twisting" has gradually become the morphological choice of many city landmark buildings in recent years. The form seems more likely to be driven by the interaction of aesthetics and structural engineering. Environmental performance is often a secondary consideration; it is typically not simulated until the evaluation phase. Based on the research results of "DigitalFUTURE Shanghai 2017 Workshop - Wind Tunnel Visualization", an approach that can be employed by architects to design environmental-performance buildings during the early stages has been explored. The integration of a dynamic form-finding approach (DFFA) and programming transforms the complex relationship between architecture and environment into a dialogue of computer language and dynamic models. It allows the design to focus on the relationship between morphology and the surrounding environment, and is not limited to the envelope form itself. This new concept of DFFA in this research consists of three elements: 1) architectural form; 2) integration of wind tunnel and dynamic models; and 3) environmental response. The concept of wind tunnel testing integrated with a dynamic model fundamentally abandons the functional definition of the traditional static environment simulation analysis. Instead it is driven by integral environmental performance as the basic starting point of morphological generation.

Keywords: Wind environment, Dynamic models, Form-finding, Twisting building design, Wind tunnel

1. Introduction

Newly-designed high-rise buildings, both in China and abroad, have demonstrated new innovations from the creative concept to the creative method. from the creative concept to the creative method. At the same time, digital technology has enabled more design freedom in the vertical dimension. Twisted, rotated, tilted, irregular, ambiguous, dynamic or plastic forms have become the novel semiotics of tall building design. In particular, the emerging twisted-form high-rise buildings indicate new thinking in the design field; these singularly-shaped buildings greatly expand the traditional conception of skyscrapers, as compared to monotonous rectilinear boxes.

The Council on Tall Buildings and Urban Habitat (CTBUH) (2016) revealed that there are currently 28 twisted tall towers between 93 and 632 meters in height, which have either been built or are under construction, while these twisted buildings are generating a new landmark building tendency. Representative buildings include the Shanghai Tower, Cayan Tower in Dubai and Absolute World Towers in Canada.

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However, the high-rise buildings designed with such methods are likely to be a source of concern for structural engineers. The architectural form should be an interface between the external natural environment and interior architectural space. The driving forces of these forms are not accidental and subjective, but rather, rational parameterized controls based on environmental data (Yuan, 2016).

However, morphological elements, such as the angle and mode of rotation, may not take environmental performance into account. On the other hand, even in the contemporary architectural design phase, environmental performance simulations are often considered and employed in post-evaluation stages (Fig. 1). This artificial iterative process may not adequately consider the importance of the environment. The environmental performance should not only establish the evaluation system and feedback mechanism for the design results, but also serve as the starting point for the initial design.

Sustained attention to construction fabrication, energy flow and aerodynamic synchronization was important factor in the development of modern architecture (Li, 2015). The "environment" discussed in this paper is primarily around air flow. Due to the complexity of the natural ventilation around buildings, several factors in the site environment can drive changes in the wind field. In this condition, it is necessary for architects to take the wind as the

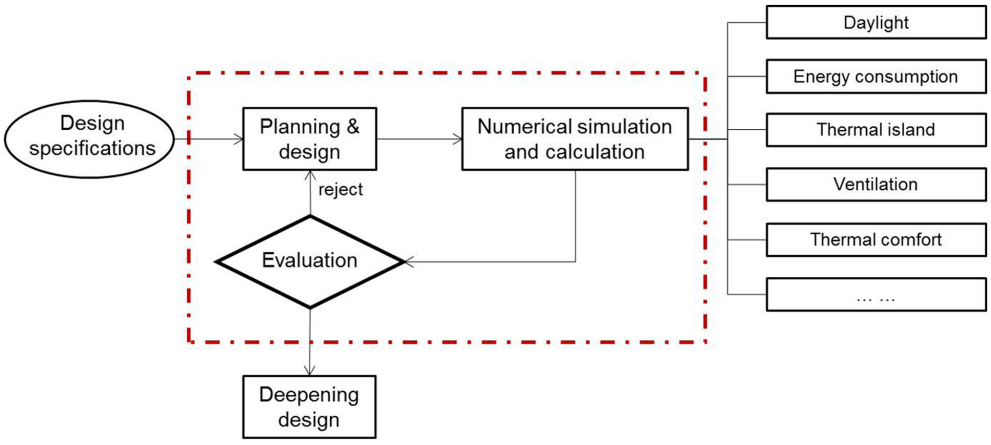


Figure 1. The post-evaluation process in a traditional environmental-performance based building design.

controlling factor in the initial stage of morphology generation.

This research proposes a morphology generation method that is beneficial to architects, according to wind environmental performance during the early stages of architectural design. Based on the principle of dynamic form finding, this method transforms the relationship between complex architecture and wind environments into computer language and a programmable, adjustable model. It prompts the design to focus on the relationship between the building and the surrounding wind environment, and is not limited to the building form itself.

2. Current Ventilation Simulation Approaches

Computational Fluid Dynamics (CFD) and physical wind tunnels have been applied in the field of flow simulation and analysis in many research papers. However, more accurate simulation results require higher-precision parameter settings and mesh grids that require more computation time from CFD software. If there is a series of buildings that need to be simulated, the experiment might be deemed impractically lengthy.

Furthermore, the relationship between the wind and the building form through digital tools is highly complicated. On one hand, accurate simulation of fluids is a very complex process: modeling accuracy, fluid initial velocity, axial static pressure gradient settings, meshing, iteration steps and so on, will obviously influence the simulation results to a certain extent. On the other hand, the problem of interconnecting the CFD software to common architectural modeling software still needs to be resolved.

On the other hand, in most cases, wind tunnels are employed in the later stage of architectural design evaluation, or in the fields of aviation, bridge engineering and the automobile industry. Compared to the CFD simulation method, a wind tunnel has two major advantages when dealing with morphology generation: fast wind environment simulation and accurate description of fluid movement. Moreover, the strength of the physical wind tunnel is in its 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. This establishes a platform for architects to simulate the wind environment more quickly and conveniently. Wind tunnel simulation results can be visualized in a variety of ways, such as adding smoke, which can clearly and intuitively record the dynamic air flow and the formation of wind fields around buildings (Fig. 2). In addition, the simulation data of a physical wind tunnel can be extracted through electrical sensors.

Nevertheless, the limitation of applying a physical wind tunnel to generate building form is also obvious. It requires a large amount of manpower and financial resources to make and adjust the physical model continuously. During the process, the visualization of the wind flow simulation results surrounds the physical model, and after the manual evaluation, the architects need to adjust or re-create the building model based on the optimized design, to simulate it in the wind tunnel again. It's clear that the optimization is a process of artificial iteration and evaluation, which greatly depends on the designer's experience in assessing environmental performance.

3. Dynamic Form-Finding Approach

In the initial stages of design, the purpose of performance simulation is not to obtain accurate environmental performance information, but to observe and manipulate the trend of behavior changes driven by natural forces (Yuan, 2016). The method proposed in this paper is performance-oriented, with passive strategies as its mainstay, supplemented by proactive strategies. Taking the performance targets of the wind environment as the driving

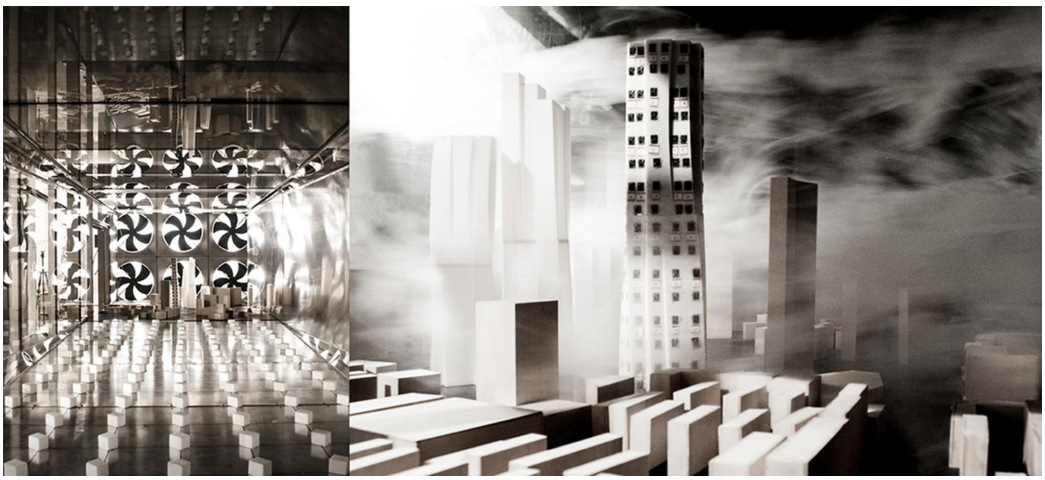


Figure 2. The experimental environment in a laboratory wind tunnel (left) and with smoke visualization (right).

parameters in the design generation and optimization process enables architects to be responsible for the environment, which brings realistic rather than subjective or arbitrarily calculated design decisions. In the early stage of design, the form self-creation and self-generation are realized through the environmental performance simulation earlier than the formal form. With the aid of physical wind tunnel simulation, environmental data are transformed into performance data, and then converted into geometric parameters, through the operation of the algorithm and logic that achieves optimized environmental-performance building morphology generation.

3.1. Principle

Deleuze's idea of “smoothing space” embodies the intelligent interaction between architecture and the environment from a philosophical, metaphysical perspective. The building in one space is constantly changing and continues to evolve, and the factor that affects the form and space of the building is the environment around the building. Environmental changes result in the various attributes of each space, and generate timely data. After that, through the dynamic model’s continuous self-changing and assessment via synchronous comparison, it can ultimately reach a state of balance (Liu, 2013).

Urban and architectural environments possess an inbuilt kinetic capacity that allows those environments to reconfigure and adapt in response to prevalent occupation patterns drives the real-time kinetic adaptation. The built environment thus acquires responsive agency at different timescales (Yuan and Neil, 2012). The main building model can be adjusted by way of the corresponding hardware and programming, while changing the data of the environment around the building in the process of constant change leads to form discovery, corresponding to the optimal solution, as driven by continuous data acquisition and comparison. In this study, Arduino, an open-source platform that integrates software and hardware, is used to read the wind environment data and control the rotation of the machine, so as to grant the subject building in the wind tunnel the ability to “think.”

3.2. Generation equipment

The wind tunnel used in this experiment is an open source, uniform, reduced-size tunnel; its total length is 3 meters. The experiment uses “Rev. P” as the main sensor, which can sense the wind speed and temperature in the environment in real time and transmit the electrical signal of the data to the design platform. Through the conversion of the formula, the accurate wind-speed value and temperature value can be obtained. The Rev. P sensor is a thermo-sensitive wind speed sensor that provides more continuity with respect to pressure-converted air-velocity values (Moya, 2015). The sensors are arranged in a matrix in the wind tunnel around the main building models. The sensors collect a 1.5-meter pedestrian-height wind speed value, which can be evaluated by pedestrian comfort standards.

3.3. Arduino Platform

This method uses the open-source Arduino platform to carry out the dynamic design of the main building model. It can not only connect to the sensor to measure and record the wind environment data, but also correlates the building model 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.

3.4. Dynamical models

The mechanical transmission of the main model brings a variety of possibilities to the building form. The rotation

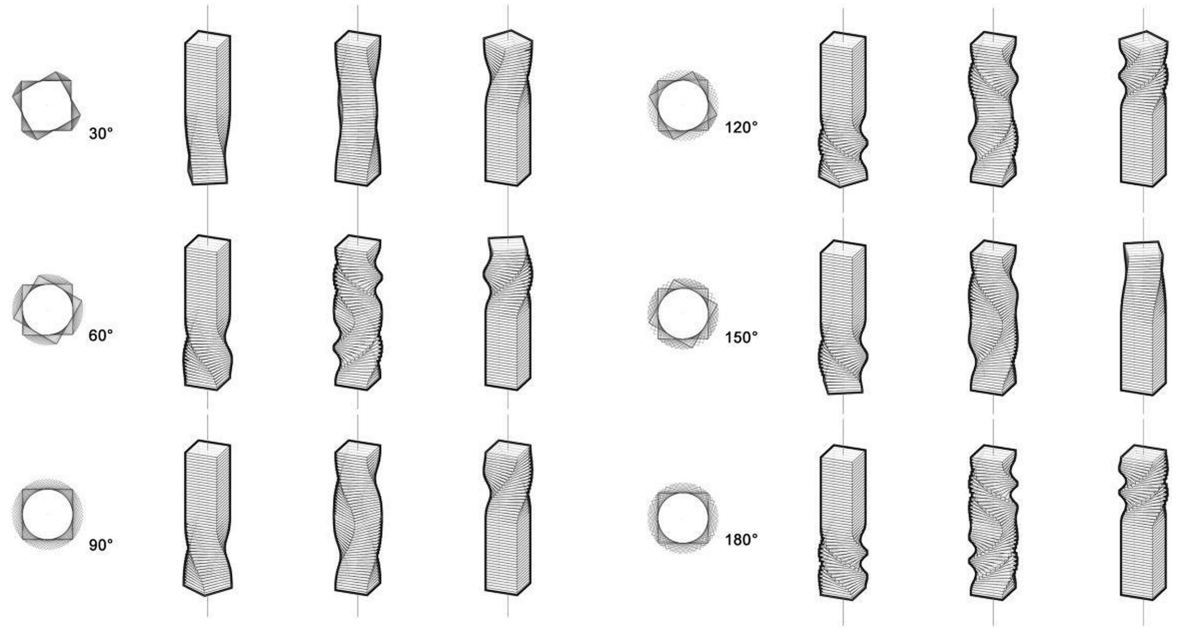


Figure 3. Twisting building morphology generation diagram.

of the steering gear can be derived from different forms of movement of the building, the rotation of the gear driven rod or other parts to complete the body model changes. The basic changes mainly consist of twisting, translation, stretching and shrinking. Taking "DigitalFUTURE Shanghai 2017 Workshop - Wind Tunnel Visualization" as an example, twisting was chosen to be the main movement mode. The twisting building morphology generation is described in Fig. 3.

Dynamic building models' production needs to consider the penetration of the wind and the integrity of the volume and other issues. Therefore, the experimental building models are composed of 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. Each model has 50 layers in total. Among them, there are three active rotating plates, and the rest are passive rotating plates. As shown in Fig. 4, the three active rotating plates of the model were controlled by three different servos, which drive the three rotating shafts that are nested together to twist through the steering gears' transmission. The three axes of rotation are made of hollow plastic tubes, which respectively transmit the rotation of the corresponding servos to the corresponding active rotary plate. There are four flexible lines inside the building model throughout, enabling the active twisting plates to drive the passive rotating plates to twist while immobilizing two sides of the building model. It tries to keep consistency of the entire model's movement. Compared with elastic skins such as latex films, the tension of elastic threads is smooth; therefore it can pull each passive rotating plate to twist without affecting the rotation of the servos.

3.5. Generation logic and process

The genetic algorithm used in this research is based on the imitation of the "survival of the fittest" principle in the process of biological evolution in nature, which develops a random global search and optimization method. It is usually applied in the research of a large number of environmental performance and architectural design parameters. The optimized building shape is dynamically screened by establishing the genetic algorithm behind the diagram, that is, the mutual organization and constraint of parameters. The genetic algorithm will randomly generate a certain amount of individuals into a generation of the population, which will then be assessed for fitness and sorting, through the analysis of each individual. Furthermore, the fitter individuals are more likely to be selected in the next generation of the breeding process, followed by the ultimate selection of the optimal solution.

The generation logic applied in this paper consists firstly of collecting different building morphology data and corresponding environmental data measured by sensors, then comparing the average of the environmental data collected during a certain period of time (iteration steps) with the comfort value. After that, the optimal value is screened out, and the building model then returns to the correspondent form with the optimal value through the list (Fig. 5).

3.6. Advantages

Although the physical wind tunnel can simulate wind environment data, the modified design still needs to regenerate the physical model for the next physical wind

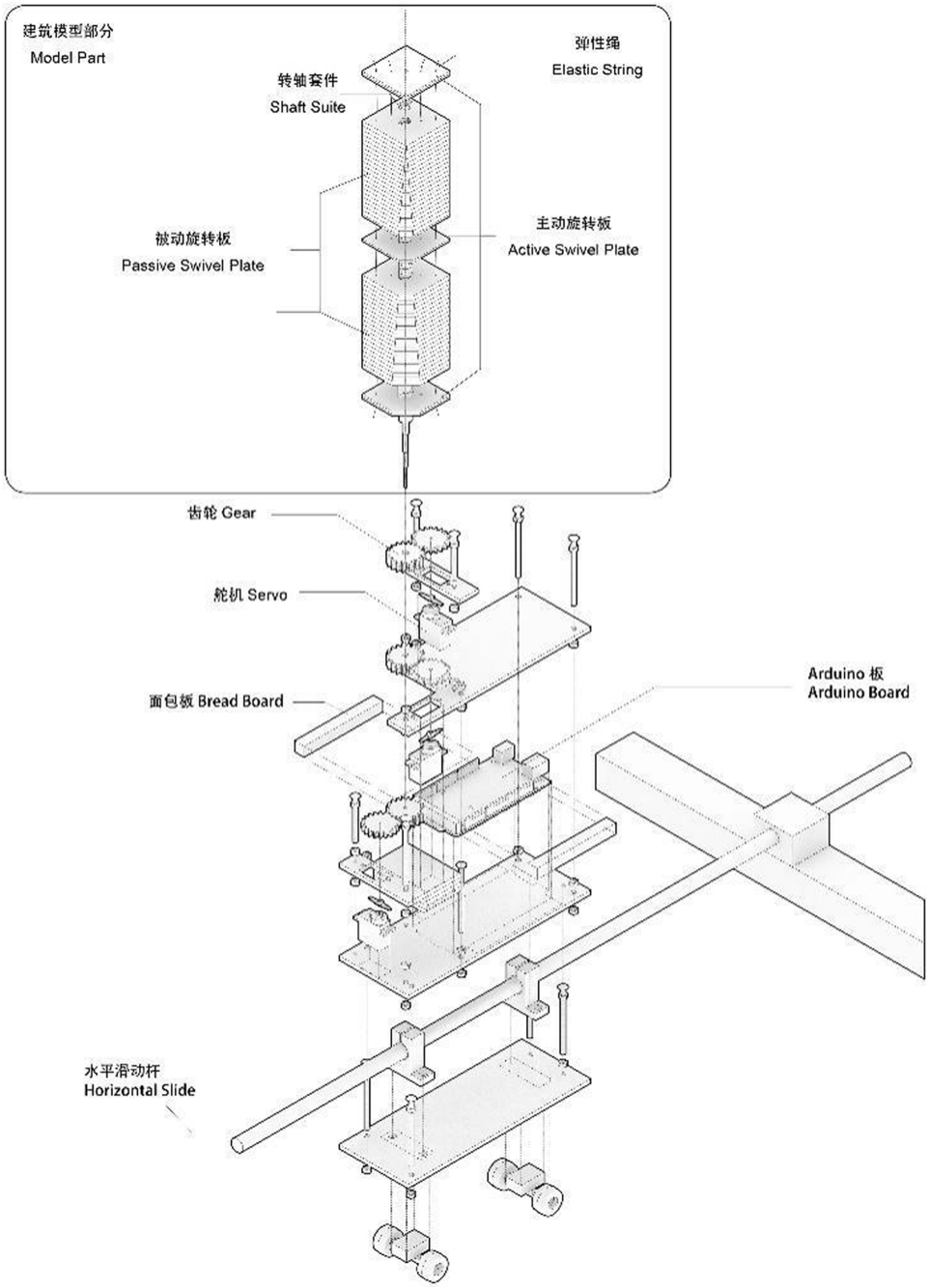


Figure 4. Dynamic model: exploded axonometric view.

tunnel’s re-simulation. In fact, the program model is unable to update instantly in the wind tunnel, which indicates the “post-evaluation” mode. However, the dynamic form finding approach involves the mechanical dynamic model, which indeed changed the previous mode so that the design model can adjust by itself in real time, according to the wind speed obtained through the sensors. Therefore, it creates a tight coupling between “performance evaluation” and “design optimization”. The optimization speed is promoted and the instantaneous environmental performance-driving morphology generation has been realized.

4. Results

During “DigitalFUTURE Shanghai 2017 Workshop - Wind Tunnel Visualization”, three dynamic building models were installed in a wind tunnel for simulation and visuali- zation, to find out the optimal respective building morphologies and arrangements for a group of buildings (Fig. 6). DFFA has brought a variety of advantages for twi-

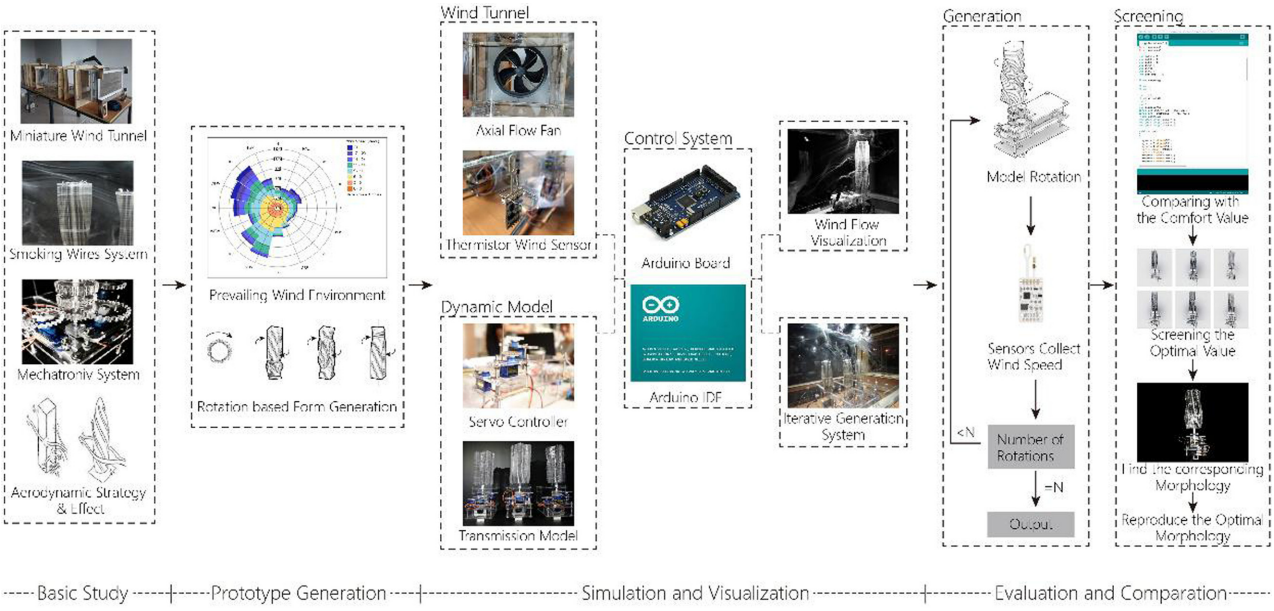


Figure 5. The workflow of the architectural generation method, combining a physical wind tunnel and a dynamic model.

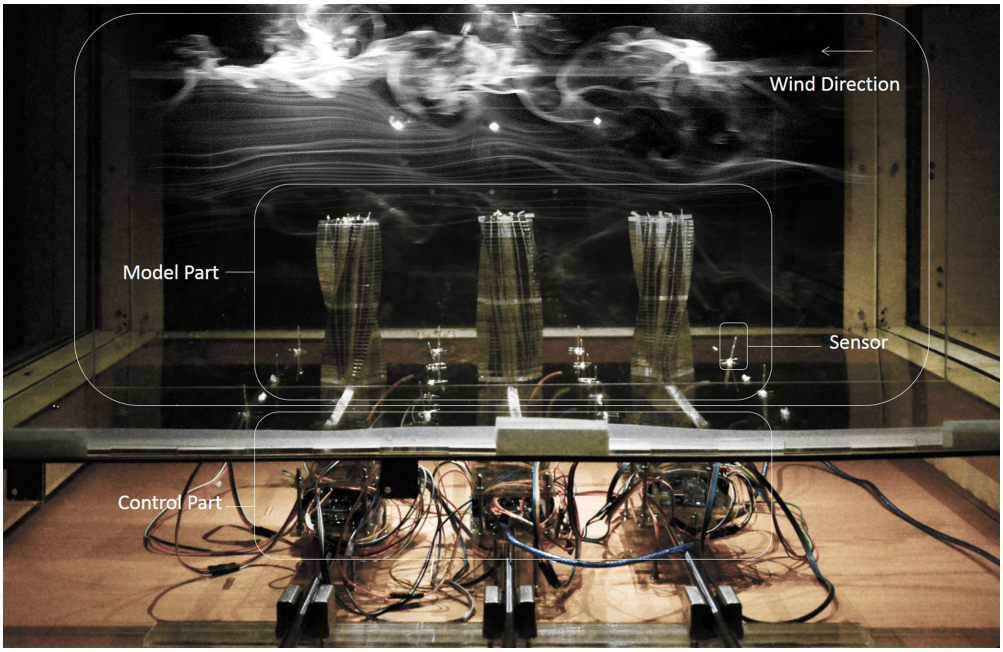


Figure 6. Dynamic form-finding models in wind tunnel.

sting building design: 1) the standard layer prototype can be designed more freely; 2) the models' movement mode can be diversely designed, for instance, through the translation and other movement modes, and the models' arrangement can also be dynamically changed; and 3) the number of active rotating plates or servos can be adjusted to create the changeable morphology. This workshop has proved that, according to DFFA, environmental performance driven building morphology generation is under rational parametric control.

5. Conclusions

From vision-driven to performance-driven, the conversational relationship between architecture and the environment has returned from the passive response of an active system to the morphogenesis-driven dynamic response. In this research, the role of environmental performance in

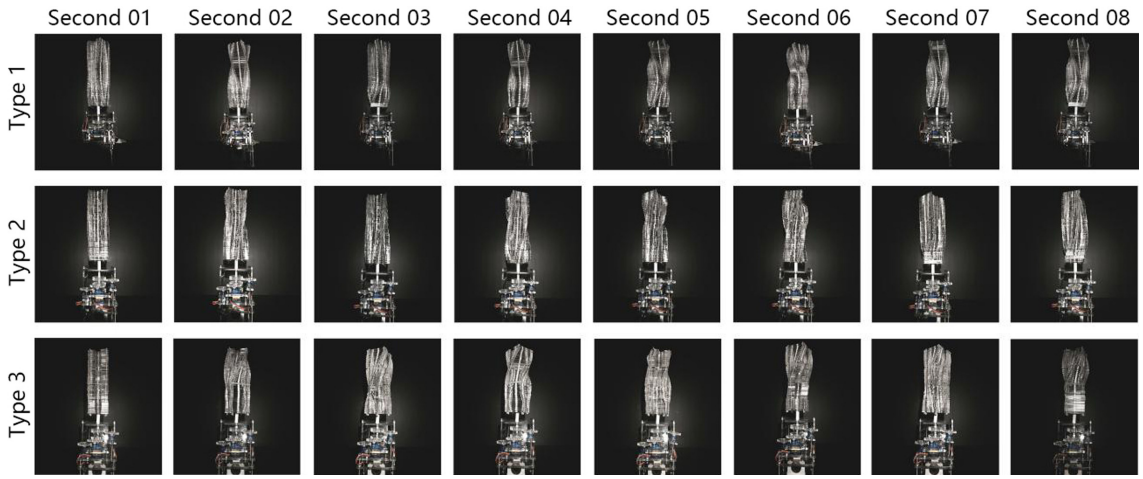


Figure 7. The final results of the generation method based on wind tunnel and dynamic model in DigitalFUTURE 2017.

architecture design is also moving away from the theory driven design approach towards the bottom-up approach, which relies on modeling and analyzing data, and then returning to the design itself. With applying DFFA, a number of wind-driven morphology generation problems have been solved. It has proved that DFFA changes the current post-formative assessment model and performs a great design derivative and potential. When facing a new twisting or other kinds of building morphology, it will no longer be confined to aesthetics or space experience, but also well considered about its environmental performance.

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