



High-Rise Building Group Morphology Generation Approach Based on Wind Environmental Performance

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Abstract. In the urbanization process, high-rise is favored and popularized, while results to the high-density urban space which aggravated the deterioration of urban wind environment. Using quantifiable environmental factors to control the building, is promoting a more meaningful group formation of the sustainable high-rise buildings. Thus, taking wind performance into account in high-rise design infancy is essential. According to the achievement of CAADRIA2018 “SELF-FORM-FINDING WIND TUNNEL TO ENVIRONMENTAL-PERFORMANCE URBAN AND BUILDING DESIGN” workshop, a preliminary set related to the environmental performance urban morphology generation system and method was constructed. In this study, various of high-rise building forms that might be conducive to urban ventilation were selected, such as “hollow-out”, “twisting”, “façade retracting” and “lift-up”, to design the Dynamic Model System with multi-dimensional motion.

Keywords: High-rise · Group morphology · Wind tunnel · Dynamic models · Environmental performance

1 Introduction

With the advance of the “Performative Urbanism” Design paradigm, it has become a design trend to bridge the urban morphology to the social aspects through the parametric design tools [1]. Applying environmental performance as driven parameters in the design generation and optimization process help the architecture decisions become more environmentally responsible and reality-based, rather than subjective and empirical as usual.

In the urbanization process, high-rise is favored and popularized because of its intensive and comprehensive nature, but at the same time it results to the high-density urban space which aggravated the deterioration of urban ventilation, heat island effect, air pollution and so on. The bulky volume of the high-rise and the formation of the numerous clusters, impacts malignantly on the outdoor wind environment through the overall effect of the wind funnel effect in the urban space, which Leads to wind retention and local eddies as well as local strong winds such as high-rise winds and corner winds, strongly affect pedestrian comfort and safety [2]. Meanwhile, the wind

direction and wind speed greatly affect the location and strength of urban heat island phenomenon [3]. Therefore, it's worthwhile to study the high-rise buildings' group formation design based on wind environmental performance, through the adjustment of the morphology and layout of the building group, thus to reduce the deterioration of outdoor wind-heat environment.

With the proposed of "Arcology" in the 1960s, wind is more usually to be regarded as an important ecological factor to drive the layout and shape of buildings through digital design approach [4]. It's a trend to adjust the pedestrian wind environment and urban bioclimatic conditions from the urban planning level [5, 6]. The building morphology generation approach based on environmental performance, using quantifiable environmental factors to control the building, is promoting a more meaningful emerge of the architectural form. Therefore, through the adjustment of the morphology and layout of the building group, the building group's morphology can interact with the trajectory of the surrounding airflow to a certain extent, and give positive feedback to the wind environment. The "City in Wind Tunnel" dynamic model device (Fig. 1) aims to explore how the morphology of high-rise buildings in high-density cities can be optimized through wind tunnel experiments, to weaken the negative impact of high-rise buildings on the post-construction environment.

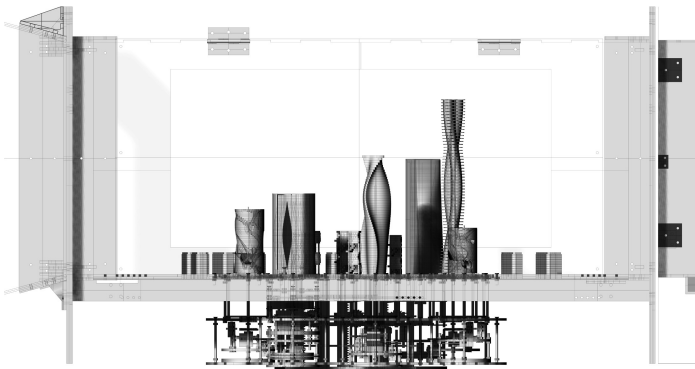


Fig. 1. The "City in Wind Tunnel" dynamic model device in CAADRIA2018 "SELF-FORM-FINDING WIND TUNNEL TO ENVIRONMENTAL-PERFORMANCE URBAN AND BUILDING DESIGN" workshop

During the previous research, a design method for the physical performance of the building morphology generation using the physical wind tunnel under the intervention of the dynamic model has been proposed [7]. The platform constructed by the method improves the feedback loop of environmental information and experimental morphology, which, at the same time, compensates for the transmission crack of wind tunnel simulation data in building generation design. Meanwhile, the integration of dynamic model abandons the functional definition of traditional static model simulation analysis that really changed the "post-evaluation" mode of environmental performance. In this condition, "performance evaluation" and "design optimization" are tightly coupled.

However, the dynamic simulation of this “self-forming” by mechanical devices based solely on a single motion change pattern can lead to limitations in the choice of building. Therefore, in this study, the author carried out the optimization design of three different motion modes of “rotation”, “shifting” and “lifting” and the corresponding control programs to achieve a more complex and diverse architectural dynamic model. Take CAADRIA2018 Workshop Group 7 A “SELF-FORM-FINDING” WIND TUNNEL TO ENVIRONMENTAL-PERFORMANCE URBAN AND BUILDING DESIGN as an example, we select twisting, setback, concave-convex façade, penetration through the volume and elevating ground floor as the morphology design strategies of high-rise buildings, which are conducive to urban ventilation. Based on the custom design of physical wind tunnels, a set of system and method for environmental performance based high-rise group morphology self-generation are preliminarily constructed, with a city-scale initial design study carried out.

2 Design Strategy

2.1 The Relationship Between Buildings’ Morphology and Surrounding Wind Environment

High-rise buildings have a strong interference with the natural flow of the surrounding wind due to their large volume. The original wind direction is forced to change when it collides with the building: part of the wind flows downwards, forming a lower wind with a faster speed, which in turn creates a vortex area in front of the building, which affects the wind field of the pedestrian height; A part of the wind can flow over the upper edge of the building to the rear of the building, resulting in negative pressure on the leeward and crosswind surfaces of the building due to the thinness of the flow, forming a wind shadow area. The two wind directions affect the local wind field around the high-rise building and form a high-rise wind. According to the flow direction of the wind, the high-rise wind is divided into a split wind and a return wind. This two actions cause the airflow to be chaotic and accelerate the wind speed to be too fast, which strongly interferes the outdoor wind environment [8].

High-rise buildings directly determine the urban spatial morphology because of their height and volume. Under the same boundary wind speed, the urban spatial morphology determines the urban ventilation to a large extent [9]. High-density urban space is prone to wind retention and local vortex, which decline the urban ventilation and self-purification capacity; local strong winds such as high-rise wind and corner wind will affect pedestrian comfort and safety; the distribution and arrangement of buildings will change the airflow direction significantly [8].

2.2 Common Forms of Contemporary High-Rise Buildings

Due to its unique humanistic attributes and scientific rationality, contemporary high-rise buildings produce a unique value system of “technical aesthetics” and “art aesthetics” that satisfy the theory of dissipative structure [10]. Based on this aesthetic

background, architects tend to select two forms of expression: “structural expressionism” and “form sculptureism” when designing high-rise buildings: the “structural expressionism” is to free the formal beauty of structure itself from a large number of cumbersome decorations for an intuitive artistic expression. This method can clearly and precisely express the structural logic of the building, and can also make the structure and space uniform expression. The “form sculptureism” is based on the sculpture method to shape the form of the building - through the addition and subtraction process, the three-dimensional space abstraction, volume sense, virtual and real relationship and detail design of the building form [11].

2.3 Case with Wind Environment Performance

In the context of the digital design paradigm, the cognition and quantitative generation of high-rise buildings based on wind environment performance has become an important method for building a livable city. The unique spatial form of the high-rise and high-density urban areas determines the urban area where the ventilation mode is various from other forms. Among them, split and return winds are formed due to the blockage of high-rise buildings, which changes the direction of airflow and increases the wind speed. At present, the influence of high-rise wind field on buildings is mainly concentrated on the windward, wind shadow areas and corner areas [8].

Through the research, the author found that the height of the building, the layout of the plane, the shape of the facade, the way of opening the window, the size of the opening and the angle between the building and the wind direction of the incoming wind may all affect the wind environment around the building. At present, the common spatial methods for the wind environment optimization are: mass transfer; morphological change; elevating ground floor; wind-proof facilities and green vegetation [12]. The wind speed fluctuation in the corner area of the building will decrease as the number of geometric edges of the building plane increases, while the torsion and scaling along the height will guide the flow of the wind. For example, the Shanghai Tower (Fig. 2) was designed with a spiral-up façade that directs the strong airflow from the corners of the building, enables it attached to the facade, spiraling up to reduce wind loads. Besides, the indentation of the windward side of the building can weaken the impact of the sinking wind on pedestrians [13]. For example, the “Abeno Harukas” building (Fig. 2) in Japan uses setback to weaken the influence of high-rise buildings on the upper wind environment as well as alleviate the vortex airflow of the windward side and downwind energy; In addition, setting “ventilation holes” penetrating through the building can weaken the impacts of strong wind in front of the building [14], reduce the scope of the wind shadow area, promote the outdoor ventilation, and optimize pedestrian comfort, such as the Pearl River Building (Fig. 2) which is designed by SOM. Thus, the research summarizes several commonly used physical strategies for optimizing the wind environment performance of high-rise buildings, including twisting, setback, concave-convex façade, penetration through the volume and elevating ground floor.

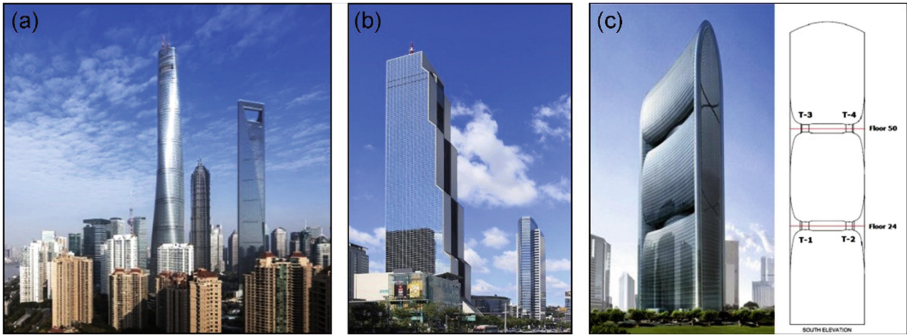


Fig. 2. Shanghai Tower (a), “Abeno Harukas” building (b), Pearl River building (c)

Since the existence of high-rise buildings has an inevitable objective impact on the surrounding wind environment, the adjustment of the building morphology and overall layout can interact with the trajectory of the surrounding airflow to a certain extent, and has positive feedback on its wind environment. Therefore, the preliminary design using the wind environment performance as a morphogenetic guide factor can effectively reduce the negative impact of high-rise buildings on the post-construction environment. This kind of environmental performance architectural design is a scientific, rational, and bottom-up design method in the digital age.

3 Dynamic Model Mechanical System Design

This paper takes the results of CAADRIA2018 Workshop Group 7 A “SELF-FORM-FINDING” WIND TUNNEL TO ENVIRONMENTAL-PERFORMANCE URBAN AND BUILDING DESIGN as an example to carry out the relevant optimization design of the physical wind tunnel and dynamic model linkage platform. The principle of the dynamic model, which composed of mechanical model device and Arduino electronic control platform, was adopted in this study for the city’s formation. The dynamic model system in the method uses Arduino, an open source platform to connect virtual information and material entities, and the corresponding motion control programs were designed for different dynamic model motion patterns. The program directly controls the parameters of different servos, that are the active parts to drive the follower through the meshing of the gears. The followers’ shape can be designed to convert the moving direction and speed of the mechanical models into the expected morphology changing mode, so that the orientation of each building model, the size of setback and the concave-convex facade, as well as the height of elevating the ground floor are enabled for continuous variation and quantitative control. Among them, each set of mechanical devices adopts standardized design, so that its position on the bottom board of the wind tunnel test section can be changed flexibly according to various design schemes. With matching different building model, which can be seen as the shells of the mechanical devices, to realize the sustainable use of physical tools.

3.1 Mechanical Transmission Principle

The mechanical transmission of the main building model provides feasibility for the diverse generation of the building morphology. The core mechanical transmission of this experiment is based on the Arduino electronic control system operating the servo system. The device controls series of different morphologies by the electronic signal generated by the wind pressure or wind speed sensor. As Fig. 3 shows, the steering gear (also known as servo motor, SERVO) is a position servo drive with an electromechanical structure of a closed-loop control system consisting of small DC motors, variable speed gear sets, adjustable potentiometers, control boards and other components [15]. The workflow is as follows: (1) The controller of the steering gear drives the motor to rotate by receiving the signal source; (2) The gear set receives the motor signal, and processes it to rotate the corresponding angle; (3) The potentiometer follows the gear set Synchronous rotation, measure the angle of rotation; (4) The board receives the potentiometer signal to determine whether the servo is rotated and maintained at the target angle. The experiment completes the morphological change of the main body model by driving the gears or other parts through the steering gear [16].

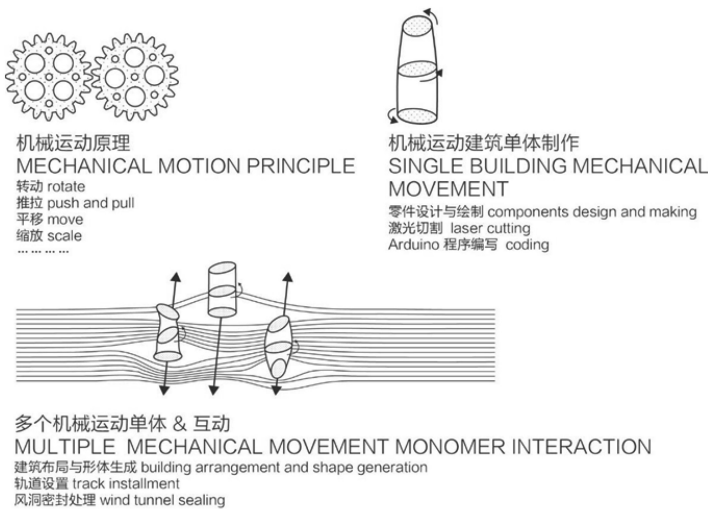


Fig. 3. Schematic diagram of the servo system in twisting model

3.2 Combination of Various Mechanical Transmission Mechanisms

Based on the three transmission mechanisms, which are rotation, shifting and lifting, the “City in Wind Tunnel” dynamic model device selects the high-rise building forms that are favorable for urban ventilation, such as twisting, setback, concave-convex façade, and penetration (Fig. 4), to carry out the mechanical system design of the dynamic model, with the corresponding control programming. The programming code controls the signal parameters of the servos, utilizing the gears as the active part to

mesh the experimental model to perform the driven motion to generate the expected form. The direction and speed of motion of the follower are controlled by Arduino, an electronic platform, so that the orientation of each building model, the size of twisting, setback, the concave-convex facade and penetration through the volume, and the height of the elevating ground floor are realized to achieve continuous change and quantitative control. Among them, each set of mechanical devices adopts standardized design, which can flexibly to be changed its position on the bottom board of the wind tunnel test section according to different design schemes, and match different building forms (i.e., the main part of the building model) to realize the sustainable use of physical tools. The number of servos increases the diversity of motion throughout the system, resulting in richer morphologies.

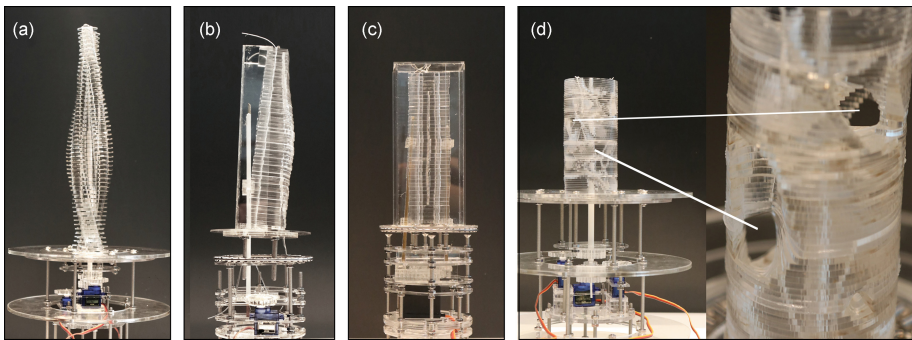


Fig. 4. Dynamic model of twisting (a), concave-convex façade (b), shifting penetration (c), rotary penetration (d)

Twisting Model

The twisting model (Fig. 5) consisted of a stack of several 4 mm thick laser-cut acrylic boards. Several active rotating boards are settled on the upper, middle and lower sides of the model according to different schemes. Besides, the remaining acrylic boards are placed between the active boards as the passive rotating boards. For instance, there're four active rotating boards of the main building model in Fig. 6 (left), which are controlled by four different servos, and the servos rotates the gears to drive the four rotating shafts that are nested together to rotate. The four rotating shafts are all made of hollow ABS tubes, so that to respectively transmit the rotation of the corresponding servo to the corresponding active rotating board. Inside the building model, a set of rotating shafts and two elastic threads are inserted. After the first and last ends of the threads are fixed, the active boards can drive the passive boards to rotate, maintaining the continuity of the entire model's motion. The elastic thread has a moderate elastic force, so that it can avoid the affect by the rotation of the servos while pulling the passive rotating boards for rotation [17].

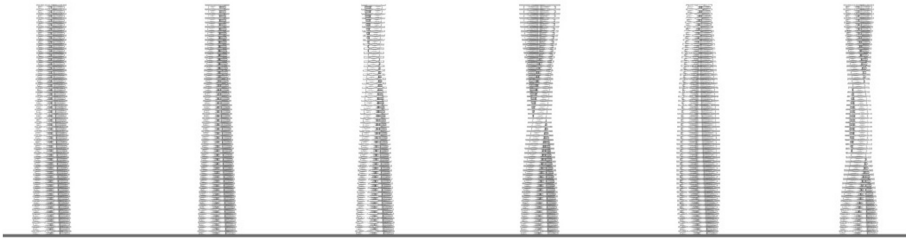


Fig. 5. Dynamic change of the twisting model

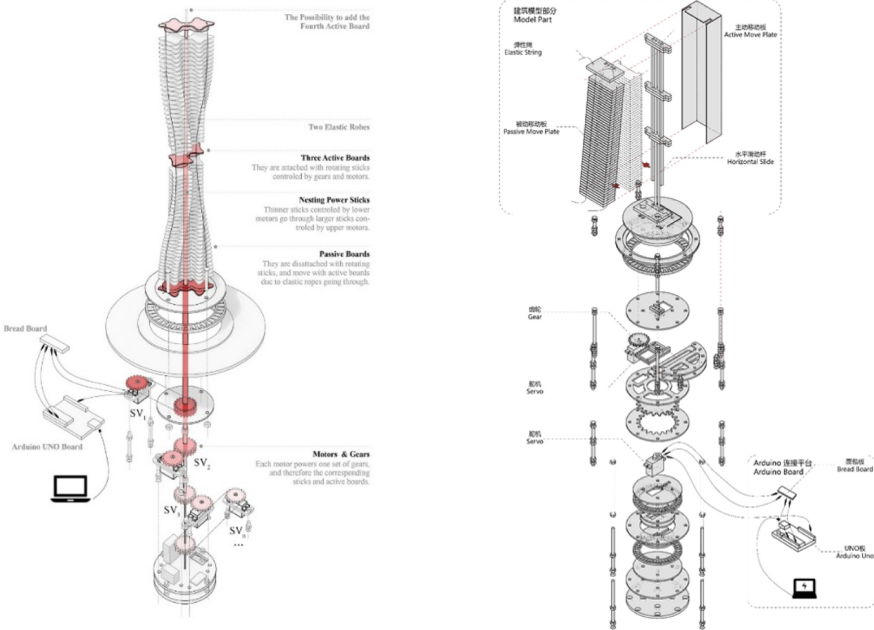


Fig. 6. Construction diagram of the twisting (left) and concave-convex (right) model

Concave-Convex Model

The concave-convex model consists of motion parts and a static cuboid enclosure. The passive part of the motion parts is formed by a stack of 4 mm thick laser-cut acrylic boards, while the active part is composed of a horizontal sliding rod arranged in the middle of the building model, and an active shifting board placed in the upper middle and lower parts. As Fig. 6 (right) shows, the active shifting boards are controlled by first servo synchronously, which drives the rod to move through the rotation of the gear, and then transmits the corresponding moving signal to the corresponding passive moving boards. The second servo, as to produce another kind of motion, that is, rotation, to realize the changing of the orientation of the building. The interior of the

building model runs through two elastic threads, the principle is the same as above. The experimental model simulates the unevenness of the facade of the building by moving the board forward and backward in the horizontal direction.

Penetration Model

The experiment of penetration through the building volume includes shifting penetration and rotary penetration. The shifting penetration building model (Fig. 7) consists of the inner driven part and the static enclosure parts on both sides. As Fig. 8 (right) shows, the dynamic part is a stack of 4 mm thick laser-cut acrylic boards, which is symmetrically distributed along the central axis of the long-side of the building model. In the middle of the dynamic part and the static part, a horizontal sliding rod is disposed

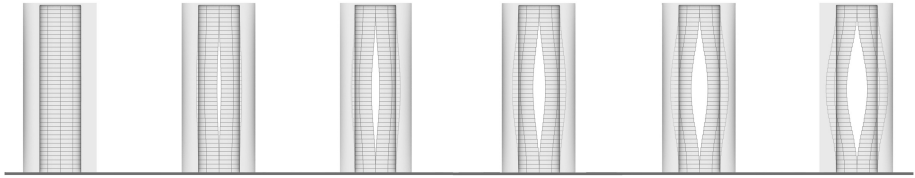


Fig. 7. Dynamic change of the shifting penetration model

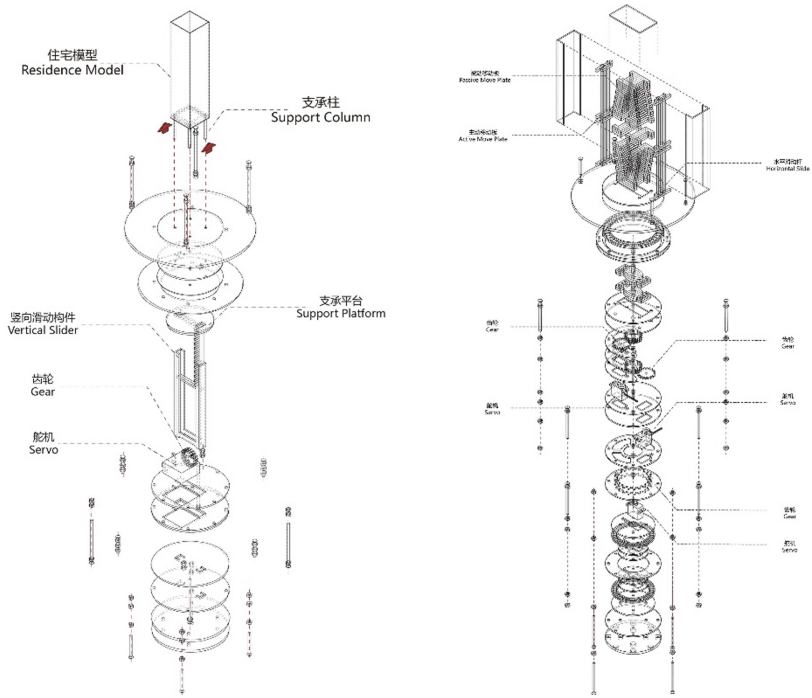


Fig. 8. Construction diagram of the elevating the ground floor (left) and shifting-penetration (right) model

on each of the left and right sides, and each of the two rod members has an active motion board in the middle thereof, which are respectively controlled by different servos. The two servos drive the left and right horizontal sliding rods to mirror the horizontal sliding by the rotation of the gears. The sliding member further transmits the motion trend to the active moving board and drives the passive moving board to perform mirrored follower motion along the long-side central axis. There are two elastic threads running through the inside and outside of the building model. The principle is the same as above.

It shows the section diagram of rotary penetration in Fig. 9, which's principle is similar to that of twisting, which's motion is based on the rotating motion mechanism. However, the model is a stack of 4 mm thick laser-cut acrylic which are punched inside in advance to simulate the internal holes of the building in a variety of internal spatial forms. The model is provided with four active rotating boards from top to bottom, and the remaining boards are regularly stacked between as passive rotating boards. The four active rotating boards of the main building model part are controlled by four different servos. The servo rotates the gears to drive the four rotating shafts that are nested together to rotate. The rest of the principle is the same as the above-mentioned "twisting" model. This experiment forms a different internal penetration space form by rotating the boards.

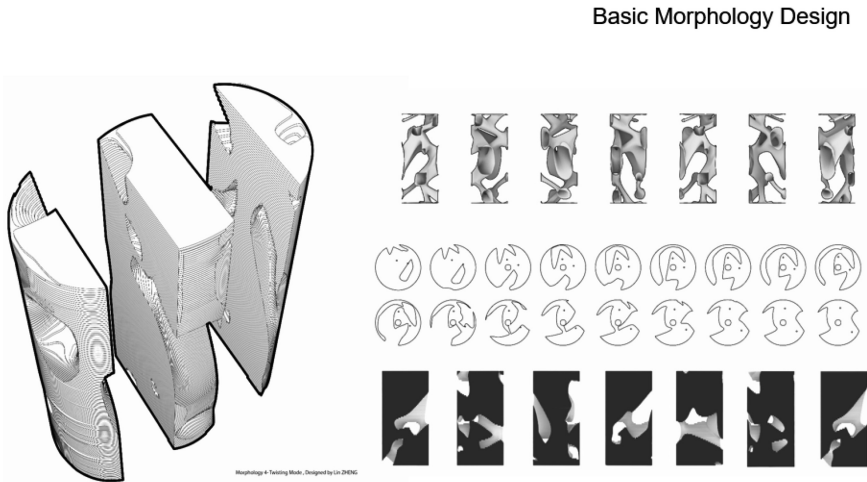


Fig. 9. Section diagram of the rotary-penetration model

4 Generation Workflow

(See Fig. 10).

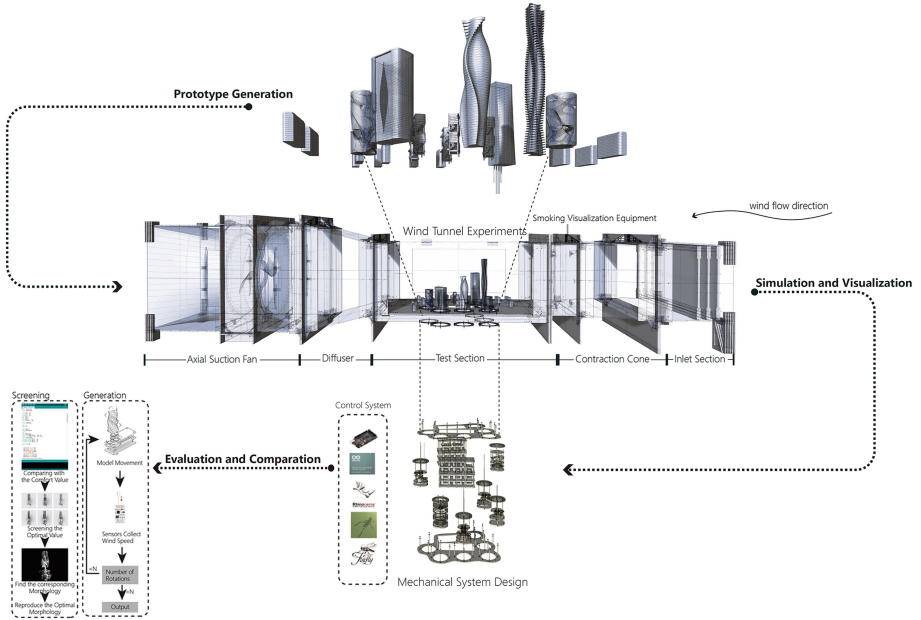


Fig. 10. Generation system based on wind tunnel experiment

4.1 Urban Wind Environment Assessment Method

The prerequisite for achieving a good urban wind environment is to be able to make scientific, reasonable and practical evaluations of the wind environment in urban design. As an analysis and generation tool [18], the algorithm can evaluate the environmental data obtained by the experiment and convert it into an environmental performance score that meets the designer’s requirements. Because high-rise buildings are more likely to form strong undershoot airflow than multi-storey buildings, the surrounding ground wind speed is four times that of low-rise buildings, pedestrian comfort is greatly affected [13], while high-rise and high-density urban center area is a densely populated area, more attention should be paid to the wind environment at the pedestrian level. Therefore, in this experiment, the wind speed is measured at a pedestrian height of 1.5 m as the basic data of the wind environment evaluation.

Since the influence of the building on the surrounding environment differs from various specific site, the layout of the sensors’ measuring position on the baseboard of the wind tunnel is depend on the design requirement, according to the criticality of social attributes such as the functional elements and crowd objects at various points around the building. Since the air flow at the pedestrian level is complex and variable, it

cannot be judged only from the wind speed value. At present, the common evaluation methods of wind environment data, such as wind speed probability evaluation, thermal comfort evaluation, wind speed ratio, wind speed dispersion, comfortable wind speed ratio, etc., can be used as a standard for constraining the building morphology generation. In this study, in the evaluation of the wind environment comfort of pedestrians, it is necessary to eliminate the building form that causes excessive wind speed dispersion. Secondly, the form with low comfortable wind speed ratio is also need to be avoided. Then, determine the range of the comfortable wind speed based on the summer average temperature value in the site environment, and obtain the different wind speed probability values of the same measuring position through a certain time measurement, so as to comprehensively evaluate the wind environment performance of the building form. Thus, three valid criteria in the wind environment evaluation—the deviation value V_{de} of the comfort temperature, the discrete value V_{di} of the wind speed of the measuring point, and the probability of the uncomfortable wind speed value P_{uc} are selected to evaluate the effective data generated in the experiment. The weight of different measuring point of the overall environmental performance score in the scheme x and the weight of the different environmental evaluation indicators:

$$E(x) = aV_{de} + bV_{di} + cP_{uc} \quad (1)$$

If the difference in criticality of each measuring point isn't obvious, the weight of the environmental data evaluation can be set to: $a = 70\%$, $b = 15\%$, $c = 15\%$, while for the homogeneity of the surrounding airflow, the evaluation weights are: $a = 60\%$, $b = 30\%$, $c = 10\%$ [20].

4.2 Optimization of High-Rise Building Group Layout

The urban space porosity is reduced when high-rise buildings form a cluster layout, which worsen the street natural wind environment permeability and make the urban pollutants more difficult to be eliminated in time, resulting in more serious environmental pollution. Therefore, in this study, the initial step is to control the spatial position of each high-rise building model and optimize the overall layout combination [5].

The orientation and layout of high-rise buildings should be staggered as much as possible, and sufficient space should be reserved between the buildings to prevent the formation of narrow-tube effects. The front and rear high-rise buildings should be staggered to reduce the wind blockage of the front-row buildings and on the main wind channel. Properly setting up squares and connect open areas of the block is to ensure that the prevailing wind of the main air duct can penetrate all corners of the area, reduce the scope of the wind and shadow area, and optimize urban ventilation [19]; the building combination should adopt a gradual height distribution, which is beneficial to reduce The sudden change of wind speed; under the premise of ensuring that sunshine meets the standard, the building is oriented to reverse the appropriate angle, which is conducive to saving land and obtaining a better wind environment [20]. Therefore, in the experiment, we use the building permeability (P-building permeability) and the site coverage ratio (λ_p -site coverage ratio) as reference factors to make a simple evaluation and optimization of the overall layout of the experiment [21].

4.3 Optimization of High-Rise Building Morphology

After optimizing the layout of the main model, this section focuses on the calculation logic of the servo factor in the iterative algorithm. By quantitatively translating a series of spatial servo data of the building model in time dimension into a mathematical language that can be scored and compared, and then weighting calculation, screening and comparison by pre-set wind environment assessment criteria, the best value is obtained and the building form is reappeared. The servo calculation logic is specifically described below in combination with model motion of twisting, concave-convex, penetration and elevation.

The principle of the twisting model is that the servos drive the building plane to rotate and generate the twisting morphology. Its deformation angle can be quantitatively controlled by four servos through controlling their degree of rotation, that is, in combination to be the degree of distortion. The rotation angle of the active board is proportional to the servo's angle. The servo angles are D_{sv1} , D_{sv2} , D_{sv3} , \dots , D_{svn} and the degree of deformation can be quantitatively expressed by the formula:

$$N = \left(\frac{D_{sv1}}{D_{sv2}} + \frac{D_{sv2}}{D_{sv3}} + \dots + \frac{D_{svn}}{D_{sv1}} \right) / n \quad (2)$$

The concave-convex model is changed by the servo driving the active board for forward and backward telescopic movement. The form variable can be quantified as the displacement distance of the active moving board controlled by the three servos, that is, the indentation rate. The moving distance of the three active moving boards is proportional to the rotation angle of the corresponding steering gear. The degree of deformation can be expressed by the formula:

$$T = \left(\frac{|D_{sv1} - D_{sv2}|}{D_{sv2}} + \frac{|D_{sv2} - D_{sv3}|}{D_{sv3}} + \dots + \frac{|D_{svn} - D_{sv1}|}{D_{sv1}} \right) / n \quad (3)$$

The calculation principle of the penetration model is more complicated, and the author summarizes it into continuity. The principle of shifting penetration is similar to that of concave-convex facade. The volume change of the form can be visually expressed as the displacement distance of the active moving board, which can be quantified by:

$$K = (D_{sv1} + D_{sv2} + \dots + D_{svn}) / n \quad (4)$$

In the rotary penetration, the penetration portion only undergoes shape adjustment during the deformation process, and its volume doesn't change. Therefore, the principle of rotary penetration is that the servo drives the hollow space of the building to undergo torsional deformation. The calculation of "emptiness" can be equivalent to the previous calculation of "torsion". The quantitative formula is:

$$R = \left(\frac{D_{sv1}}{D_{sv2}} + \frac{D_{sv2}}{D_{sv3}} + \dots + \frac{D_{svn}}{D_{sv1}} \right) / n \quad (5)$$

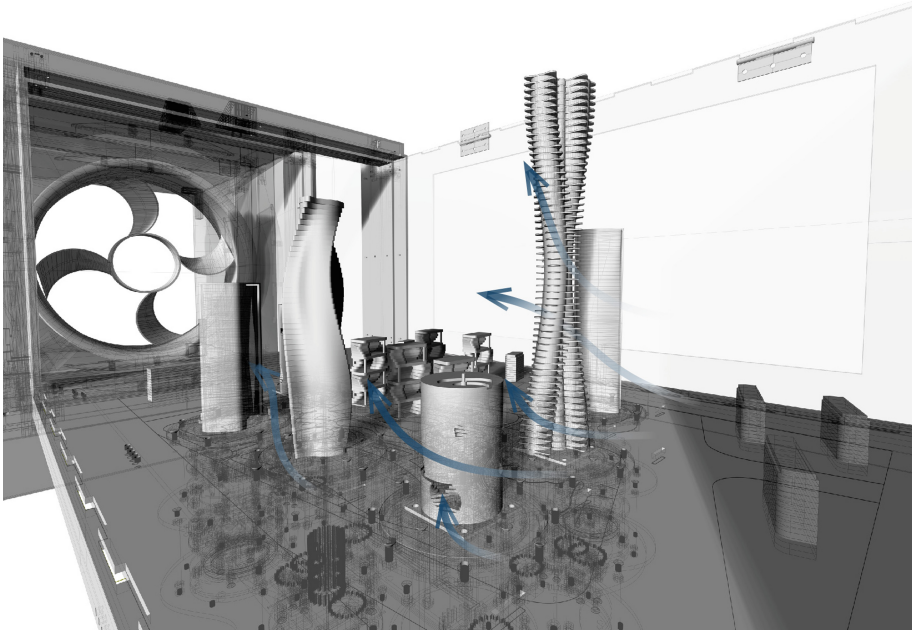


Fig. 11. Simulation diagram of the wind tunnel experiment

5 Summary

The design of the “City in Wind Tunnel” experimental device developed the multi-dimensional motion mechanism, which enables the physical building models to generate active and dynamic feedback changes to its environment (Fig. 11). The interactive programming technique combined with environmental performance and digital building profile algorithm brings a new definition of non-deterministic patterns and convertible properties to the dynamic model. With the help of the new parametric design platform, designers can instantaneously obtain a large number of different physical data in the same environment background, satisfying the requirements of machine learning for massive sample data such as genetic algorithm or neural network algorithm, and bridged the building geometry generation parameters and urban wind environment parameters.

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References

1. Yuan, W., Xu, W.: Research on algorithmic shape based on environmental performance analysis. In: 2013 National Architectural Institute Digital Architecture Teaching Seminar and International Symposium on Digital Architectural Design, Tianjin, China (2013)
2. Yang, X.: High-rise building shape design strategy under the influence of wind environment. Tianjin University (2014)
3. Oke, T.R.: City size and the urban heat Island. *Atmos. Environ.* (1967) **7**(8), 769–779 (1973)
4. Lan, M.: Create a harmonious environment together of ecological architecture design method. *Procedia Environ. Sci.* **10**, 1774–1780 (2011)
5. Ng, E., et al.: Improving the wind environment in high-density cities by understanding urban morphology and surface roughness: a study in Hong Kong. *Landsc. Urban Plann.* **101**(1), 59–74 (2011)
6. Kormaníková, L., et al.: Parametric wind design. *Front. Archit. Res.* **7**(3), 383–394 (2018)
7. Lin, Y., Zheng, J., Yao, J., Yuan, P.F.: Research on physical wind tunnel and dynamic model based building morphology generation method. In: CAADRIA 2018, Fukuda, W.H. T., Janssen, P., Crolla, K., Alhadidi, S. (eds.), pp. 165–174. Beijing (2018)
8. Xie, Z., Yang, J.: Optimization design strategy for high-rise building forms to improve outdoor wind environment. *J. Archit.* (2), 76–81 (2013)
9. Zhu, Y.: Research on the evaluation method of stroke environment in urban planning and design. Southeast University (2014)
10. Yang, Y.: Research on the aesthetic value of high-rise buildings. Chongqing University (2006)
11. Wang, R.: Conceptual design of high-rise building plastic art and structure. Chongqing University (2007)
12. Ye, Z., Chen, Y.: The spatial pattern design of urban plots oriented by wind environment: taking the plot of the school of architecture and urban planning of Tongji University as an example. In: the International Conference on Urban Development and Planning (2010)
13. Xie, Z., Yang, N.: Optimization design strategy for high-rise building shape to improve outdoor wind environment. *Acta J.* (2), 76–81 (2013)
14. Guo, F., Li, P.: Building morphing strategy based on wind environment. *Hous. Ind.* (7) (2016)
15. Hu, X., et al.: Research on semi-physical simulation system of steering gear based on virtual instrument. *J. Measur. Control Technol.* **30**(01), 75–78 (2011)
16. Cai, R.: Arduino based steering gear control system design. *J. Comput. Knowl. Technol.* **8**(15), 3719–3721 (2012)
17. Lin, Y., et al.: Research on the architectural properties of environmental performance based on wind tunnel visualization (2) (2018)
18. Maxwell, I., Pigram, D.: Algorithmic typology: towards an operational model. In: *Scripting the Futures*, pp. 107–112. Tongji University Press, Shanghai (2012)
19. Wang, H.: Research on the shape control of high-rise buildings in Shenzhen Qianhai No. 3 unit based on wind environment. Harbin Institute of Technology (2013)
20. Yao, X., Leng, H., Sun, Q.: Research on wind environment optimization strategy in high-rise residential areas. *Ind. Constr.* (s1), 9–11 (2013)
21. Yuan, C., Ng, E., Norford, L.K.: Improving air quality in high-density cities by understanding the relationship between air pollutant dispersion and urban morphologies. *Build. Environ.* **71**, 245–258 (2014)