On the Method of Architectural Formation Generation Based on the Control of Wind Environment Under the View of Micro Urban Regeneration

LI Mengshu
China Architecture Design &
Research Group
Beijing, China
shawn_lms@126.com

Jiang Menghuang
China Architecture Design &
Research Group
Beijing, China
2021023@cadg.cn

***Abstract*—This study focuses on micro urban regeneration and explores an architectural formation generation design method centered on wind environment guidance and control, aiming to improve the comfort, livability, and sustainability of urban areas. We comprehensively use Wind Engineering, Architectural design principles, and calculation methods to introduce wind environment guidance and control to optimize the building form and improve ventilation and energy efficiency. Through simulation analysis, the effectiveness of the method was verified, and implementation suggestions were put forward. This method provides a new way to improve urban micro-renewal projects and promote sustainable urban development.**

Keywords—Micro Urban Regeneration, Control of Wind Environment, Architectural Formation Generation, Sustainability, Simulation Analysis

I. INTRODUCTION

In the context of low-carbon cities and the post-pandemic era, scientifically coordinating the relationship between urban wind environment and urban morphology is essential for enhancing climate comfort and dispersing atmospheric pollution. However, during urban micro-regeneration processes, there are numerous residential areas that require environmental comfort improvements. Urban outdoor spaces serve as venues for residents' daily interactions, and people's indoor and outdoor activities are directly influenced by the comfort of the built and unbuilt space environments. Therefore, there is growing attention on the health needs of urban microclimates and building environments. Buildings alter the natural spatial wind fields, creating disturbances and obstructions that can affect the original state of the wind environment in complex ways. These changes may be beneficial or detrimental to human comfort. A comfortable microclimate is a significant factor in attracting people to public outdoor spaces, optimizing urban residents' living experiences, and promoting physical and mental health. Therefore, understanding the issues related to residential area wind environments and adopting gradual micro-renewal strategies becomes crucial for enhancing the quality of living spaces in aging neighborhoods. In this process, it is important to consider the interaction between external wind environments and building forms, respect local climatic conditions, rationally organize indoor and outdoor spaces, and create comfortable living environments. Re-examining the relationship between building form and urban climate, particularly group form and the intrinsic logic of urban wind fields, is especially important in seeking a design methodology driven by wind environment optimization at the initial stages of design.

II. CURRENT STATUS OF MICROCLIMATE RESEARCH

A. *Relationship between Human Comfort and Microclimate*

Microclimate is closely linked to human comfort and is a critical topic in urban environmental research. It refers to the climatic characteristics within a localized space, including temperature, humidity, wind speed, and direction. Human comfort indicates the level of comfort or discomfort experienced under specific environmental conditions. Factors such as buildings, street layouts, and green vegetation influence microclimate, subsequently affecting human comfort. Building features like height, shape, and material can alter the distribution and velocity of surrounding wind fields, influencing airflow, temperature distribution, and humidity. Street characteristics like width, orientation, and building density also impact wind speed and direction, thereby influencing temperature and humidity distribution. Green vegetation provides shade, regulates humidity, and reduces heat island effects, playing a positive role in improving microclimate. Researchers explore the connection between human comfort and microclimate conditions through simulations, observations, and analyses of data on human perception and response. These studies guide urban planning and architectural design, aiming to create more comfortable and healthy indoor and outdoor environments. By adjusting building forms, layouts, and material choices appropriately and optimizing the layout and management of green vegetation, microclimate conditions can be improved, enhancing human comfort and ultimately elevating urban residents' quality of life and health status. In summary, in-depth research into the relationship between microclimate and human comfort is crucial for crafting livable urban environments. This field of inquiry not only involves defining and characterizing microclimate but also requires considering human perception and response, providing scientific grounds for urban design and planning to create more comfortable and healthy urban living environments.

Table 1 Correlation between Wind Speed Values and Human Perception

Level	Wind Speed Value /(m/s)	Perceptual Characteristics
1	V < 0.3	Stagnant wind, uncomfortable
2	0.3 < V < 5	Comfortable
3	5 < V < 10	Uncomfortable, noticeable wind characteristics
4	10 < V < 15	Very uncomfortable, movement hindered
5	15 < V < 20	Intolerable, dangerous
6	20 < V	Dangerous to the point of affecting normal actions

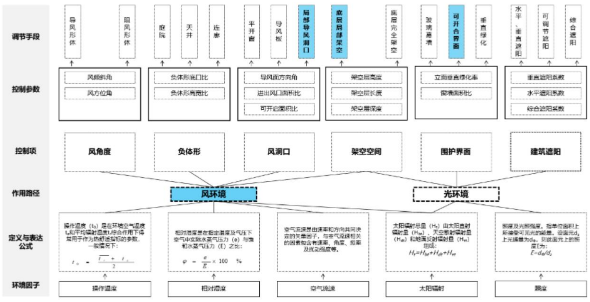


Figure 1 Factors Affecting Wind Environment

B. Development of Wind Environment Simulation and Its Directions

The cognitive process of constructing wind environments influenced by buildings has a long history. Early studies relied primarily on architects' experience and lacked scientific theories and advanced technical support. Additionally, past urban populations and planning were relatively smaller compared to today's cities. However, with technological advancements in Western developed countries and the expansion of city size, urban wind environment issues became increasingly prominent. Not until the 1960s did quantitative research on urban wind environments begin to flourish with the advent of computer technology and sophisticated techniques like wind tunnel experiments. However, applying modern scientific theories to quantitatively analyze and research urban wind environments remains a relatively young discipline. In this aspect, China started later, mainly in the 1990s. Yet, over the past two decades, thanks to continuous exploration and technological progress in both domestic and international academic and industrial circles, China has made significant progress in the field of urban wind environment research. On the other hand, the current research situation shows a diversified feature, lacking a unified theory or methodological system. This can be attributed to the complexity of urban space's impact on wind fields and differences in researchers' backgrounds and concerns, leading to variations in research objectives, significance, and methodologies. The diversity of existing research indicates that different researchers focus on specific issues concerning urban wind environments from their respective perspectives. This scattered research tendency makes theoretical and methodological integration challenging. The impact of urban space on wind fields involves multiple factors such as building form, surrounding geography, and climatic conditions, making the interaction among these factors complex and increasing the difficulty of research. Furthermore, differences in researchers' backgrounds and concerns lead to divergences in research objectives, significance, and methodologies. For instance, architects might pay more attention to the impact of building form on wind environments, while meteorologists might focus more on the relationship between meteorological parameters and wind environments. These differences result in disagreements in research objectives and method selection, lacking a holistic research framework.

Therefore, further efforts are needed to form a more unified theory or methodological system to advance the development of research on urban wind environments and buildings. This requires collaboration and exchange among researchers to integrate knowledge and experience from various fields. At the same time, a deeper understanding of the interaction between urban space and wind fields is necessary to explore more comprehensive and inclusive research methods to promote the field's advancement and application.

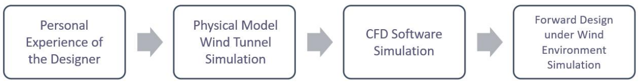


Figure 2 Timeline of Wind Environment Development

B.1 Evolution of Meteorological Information Acquisition Method

The acquisition of meteorological information for wind environment simulations has undergone significant evolution over the past few decades.

Introduction of Early Meteorological Data: Initially, researchers relied on regional meteorological data and field observations to gather required meteorological information. These data were typically obtained from databases published by the China Meteorological Administration or regional weather stations, or through setting up small weather stations at specific locations for field observations. Although this method provided some meteorological data, it had limitations and could not provide detailed and comprehensive wind environment information.

Introduction of Computational Fluid Dynamics (CFD): With technological advancements and increased computing power, the acquisition of meteorological information in wind environment simulations underwent a transformation. One significant development was the use of computational fluid dynamics (CFD) simulations for obtaining meteorological information. CFD simulation is a numerical simulation method based on computer models that can simulate and calculate complex meteorological phenomena using mathematical equations and physical models. Compared to traditional field observations, CFD simulations are more efficient and flexible, providing detailed and comprehensive wind environment information.

Introduction of Simulation Climate Models: Furthermore, other advanced technologies and tools have emerged for acquiring meteorological information in wind environment simulations. For instance, advanced numerical weather prediction models and climate models can provide more accurate and long-term meteorological data for simulating and analyzing wind environment changes and trends. Remote sensing technologies are also widely used to obtain meteorological data, such as satellite remote sensing and lidar, which can acquire real-time wind field information over large areas.

Overall, the acquisition of meteorological information for wind environment simulations has shifted from relying on regional meteorological data and field observations to employing computational simulations, numerical models, and advanced technologies. These new methods and tools provide researchers with more comprehensive, accurate, and efficient meteorological information, contributing to a deeper understanding and analysis of the characteristics and impacts of urban wind environments.

Figure 3: Evolution of Meteorological Information Acquisition Methods Meteorological Station - Computational Simulation - Numerical Model - Advanced Technologies

B.2 The Emergence and Application of CFD

With the development of computer technology, computational fluid dynamics (CFD) has been increasingly utilized in academic research and industrial practice. Compared to wind tunnel experiments, CFD is more efficient and time-saving. By utilizing CFD software, the process of computer processing information and data is faster and simpler, greatly saving the time and energy of manual calculations and improving work efficiency. It also avoids the adverse effects of various uncertainties in field research on the accuracy of experimental results. Moreover, CFD technology does not require people and objects to be in dangerous environments, making it safer than wind tunnel experiments [6]. In the past few decades, many researchers have conducted detailed studies on the wind field around individual buildings. Their research shows that by choosing appropriate turbulence models, some complex flow phenomena, such as fluid separation, vortex shedding, recirculation, and reattachment, can be accurately captured. However, the wind environment around groups of buildings becomes very complex due to the interference of factors such as layout and shape. Some scholars have conducted numerical calculations on the wind environment around simple-shaped and parallel-arranged building groups, but due to the limitations of computer conditions and turbulence models, the results were not entirely satisfactory. Furthermore, CFD simulation results need to be verified by wind tunnel experiments or actual physical flow fields to be reliable. At this point, if CFD numerical simulation technology is utilized, it can provide a comprehensive understanding of the indoor and outdoor wind environment of the building while retaining the characteristics of different design schemes. It can even simulate certain microclimates around the building and evaluate human comfort based on this. This can guide and optimize the design scheme, thereby developing a truly satisfying architectural design that meets the requirements of architects for form and function while providing a comfortable wind environment [7].

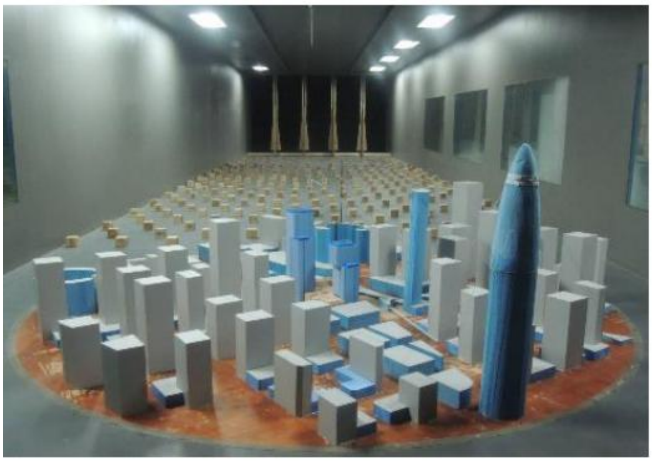


Figure 4: Wind Tunnel Experiment Diagram

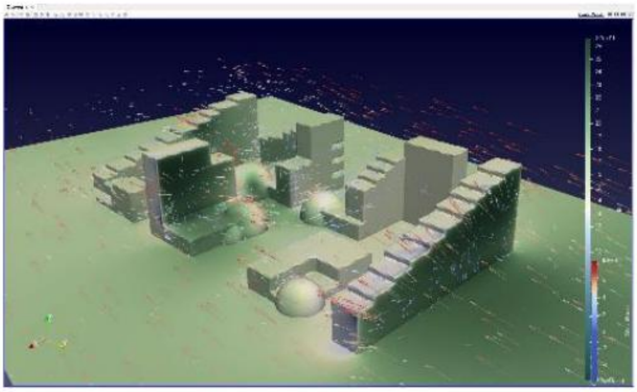


Figure 5: CFD Experiment Diagram

C. *Current Status of Wind Environment Intervention Design*

As a measure of civilization, social computing power has transformed design media through digital technology, and has also triggered changes in design thinking [8]. The interaction between humans and machines, physical reality and cyberspace has gradually become the core of digital culture. The "Ulm Philosophy" proposed in the mid-20th century, which advocates "human-computer collaboration and design science," still holds prophetic significance today with the significant increase in data and computing power. With the continuous development of performance-based simulation tools, the traditional "trial-and-error" passive design method is gradually being replaced by logical generative design [9]. Since correct decisions made in the early stages of design largely affect future energy consumption, environmental performance simulation should shift from an analytical tool to a "proactive" generative tool. However, at present, a large number of performance simulation tools are constrained by the trade-off between model detail and simulation duration, making it difficult to provide timely feedback in the early stages of design. This "post-evaluation" paradigm cannot meet the pursuit of architects for environmental performance-based design.

C.1. Introduction of Parametric Design

Parametric software enables iterative updates of architectural models. By digitally translating the architectural form into a series of adjustable data, adjustments and optimizations of the architectural form can be achieved by changing the data [10]. Based on the Rhino+Grasshopper platform, climate analysis [11], energy consumption simulation, and visualization plug-ins represented by Ladybug, Honeybee, Geco, Butterfly, Dragonfly, etc., bridge the gap between modeling platforms and energy consumption simulation platforms during the schematic design stage. This avoids errors and wastes of time and energy that may occur in the traditional performance simulation process, such as secondary modeling and model format conversion [12].

C.2 Self-optimizing Algorithms such as Genetic Algorithms

By combining plug-ins such as Galapogos, the software can automatically adjust the model and optimize the scheme through the genetic algorithm module, achieving the environmental performance-based generation of architecture [13]. The fundamental principle of genetic algorithms is to set one or several indicators as evaluation scores, select several groups with higher scores under different initial parameter combinations as parents, slightly modify them to form offspring parameters, calculate scores, and select the best, repeating this process until a group with the highest score and convergence is obtained, which serves as the optimal solution. It can be said that the iterative generation method based on digital simulation tools is actually just selecting the best from a limited number of random solutions, rather than solving from environmental performance to scheme form in reverse.

III. DEVELOPMENT OF BUILDING MICROENVIRONMENT SIMULATION SOFTWARE

A. Purpose of Software Development

A.1 Application Scenario

During the design phase of architectural schemes and during the stage of architectural form deliberation, the software simulates wind environment calculations to positively refine the design scheme.

A.2 Output Results

The software will simulate a series of building form adjustment plans after micro-adjustments on the basis of the existing scheme form, taking into account the modeling of the surrounding environment, and provide key data such as wind pressure and wind speed for calculation results. This guides the arrangement of form during the scheme stage.

B. Purpose of Software Development

B.1 Software Advantages

Data Accuracy: The software has high data accuracy, with input data downloaded from official meteorological websites, ensuring the precision of project output results by outputting results at 1m x 1m units. It is integrated with industrial design software Rhino, ensuring overall accuracy. The analysis results are slightly less accurate than professional wind environment analysis products such as FLUENT, AIRPARK, and PHEONCIS, but they meet the needs of conceptual design stages of architectural schemes [14].

Time Saving： The software's analysis and generation speed is relatively fast, allowing users to obtain results quickly, ensuring the progress of architectural project design.

Integration with Common Modeling Software： The software is integrated into architects' common software Rhino, conforming to user habits. It has low operating environment requirements, simple installation, and compatibility with other similar modeling software for model import, providing flexibility and convenience [15].

B.2 Software Running Algorithms

Due to the high computational cost of Computational Fluid Dynamics (CFD) simulations, if a full scene simulation is calculated once, the required time would be too long to apply in daily design work. Therefore, we created a multi-directional wind reduction factor matrix in the post-processing flow.

Preprocessing Related Wind Direction Data: To simulate the most relevant wind direction at the location, we cluster hourly wind directions from weather files into eight clusters (simulation budget), run RANS (Reynolds-averaged Navier-Stokes equations, same below) CFD simulations, serving as spatial wind speed matrices [16].

Spatial Wind Speed Matrix: RANS simulations can serve as nearest neighbor wind speed lookup tables consistent with annual weather data. For each detection point, we record the results of each RANS simulation speed. This multidimensional array is used to calculate dimensionless wind speeds at each detection point by dividing the simulated speed magnitude by an entry speed scaled down with a logarithmic wind power profile. This produces a two-dimensional space wind reduction array containing information for each wind direction at each detection point.

Time Wind Speed Matrix: In this stage, the spatial matrix is converted into a time matrix. For each hour of the year and its corresponding wind direction, we match the nearest neighbor CFD simulation, and multiply the speeds in the spatial velocity matrix with the scaled-down weather data wind speeds at the detection height. This operation produces a two-dimensional time velocity array containing wind reduction data, from which the wind speed for UTCI (Universal Thermal Climate Index) calculation is retrieved [17].

C. Instructions for Use

C.1 Software Operating Environment

Rhino6 or Later Versions: Needs Rhino software itself as a modeling software and for model input and output. Also requires its built-in grasshopper plugin.

BlueCFD: The software needs to call this software as the core engine for simulation calculations.

Ladybug Plugin: This plugin is oriented towards grasshopper, facilitating the extraction of regional epw format meteorological data and graphical representation.

C.2 Data Input and Output

Table 2 Software Input and Output Content

Data Name	Data Format	Remarks
Site Buildings	Brep	Surrounding Model
Facade to be Optimized	Surface	Select Analysis Surface
Form Optimization Strategy	Int(0,1,2)	Strategy Selection
Starting Boundary Position for Opening (X & Y)	Float (0.0~1.0)	
Ending Boundary Position for Opening (X & Y)	Float (0.0~1.0)	
Fillet Radius	Int	Unit: m
Analysis Precision / Cell Size	Int	Unit: m
Start of Analysis	Boolean	On/Off Switch
Building Orientation	Int	
Local Meteorological File for Project	Epw File	Specified Path
Visualization Display - Wind Speed m/s	Int	
Optimized Building Form	Brep	
Wind Environment Unit Mesh Face	Mesh	
Wind Environment Unit Surface Wind Speed	Float	Unit: m/s
Wind Environment Unit Surface Wind Pressure	Float	Unit: kN/m^2

IV. PRACTICAL APPLICATION OF WIND ENVIRONMENT SIMULATION SOFTWARE

A. Project Introduction

A.1 Project Location and Layout Features

The area being simulated is a new campus of a university in Xi'an, where a new complex of buildings is planned. A significant feature of the site is the towering Qinling Mountains located 2km south of the campus, which block the wind. The complex is situated in the northwest part of the campus, with courtyards arranged in a clustered manner. Facilities such as dining halls, swimming pools, and student activity centers are planned within the complex. To the north is faculty housing, to the east are sports facilities, and to the south is the central axis road of the campus, with an existing complex of buildings on the south side of the road. The complex borders the western edge of the campus, with historical buildings such as the Caotang Temple to the southwest.

Figure 6: Northward Aerial View of the Site

Figure 7: Westward Aerial View of the Site

A.2: Characteristics of the Project's Wind Environment

Wind Direction: The meteorological characteristics of Xi'an, influenced by topographical factors, are primarily reflected in the prevailing winds throughout the year, which are almost identical in both winter and summer.

Mountain Effect: The Caotang Campus is close to the Qinling Mountains, and the unique environmental conditions there affect the wind direction. The mountains act as a barrier to the wind, often leading to thoughts of "Qinling clouds crossing horizontally." Additionally, large mountain masses have a strong breathing effect, resulting in different directions of airflow along the terrain during the day and night, affecting the campus and the site.

Existing Buildings Around: The influence of the surrounding built environment on ventilation is significant. To the west, there is an open road; to the north, there is a densely populated faculty residential area, which acts as a windbreak; to the east, there are sports facilities, especially indoor stadiums adjacent to the southeast corner of the construction site, creating a relatively strong impact; and to the south, there is the main axis road of the campus, with the already constructed Nanshan Academy on the opposite side of the road, positioned between the site and the Qinling Mountains, exerting certain effects on the wind field of the project. After comprehensively describing the wind environment, the existing unfavorable points are listed as important restrictive factors for setting up the next steps.

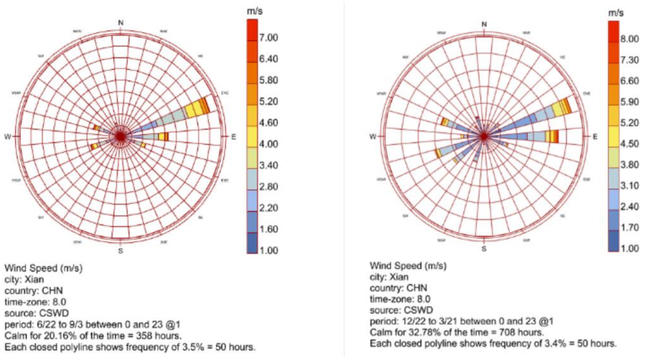
A.3: Current Wind Environment of the Project Site and Wind Issues to Consider for the Shuyuan Layout

The northern side of the site is currently occupied by faculty housing, acting as a windshield for the site. The western and southern sides of the site are adjacent to streets, which are relatively open, resulting in larger wind speed values on the ground. The eastern side of the site is occupied by sports facilities, which provide a windbreak effect.

The project's plot ratio for the Caotang Shuyuan is 3.5, indicating a high-density residential complex. The design requires setting up airflow through the site among the complex groups. Important wind phenomena such as corner wind, windshield effect, wind tunnel effect, and natural exhaust shafts need to be considered.

Figure 8: Schematic Location of Micro-Renewal Site

Table 3: Xi'an Climatic Data Statistics Table

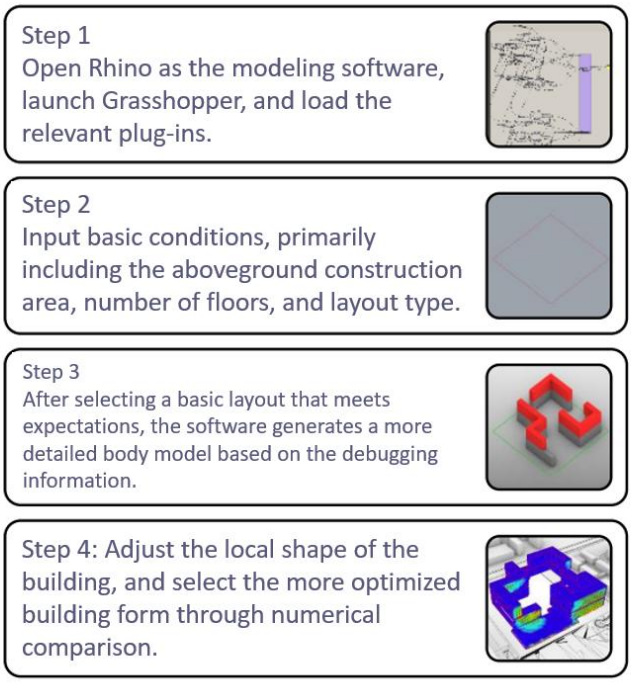


Wind Speed (m/s)
city: Xian
country: CHN
time-zone: 8.0
source: CSWD
period: 6/22 to 9/3 between 0 and 23 @1
Calm for 20.16% of the time = 358 hours.
Each closed polyline shows frequency of 3.5% = 50 hours.

Wind Speed (m/s)
city: Xian
country: CHN
time-zone: 8.0
source: CSWD
period: 12/22 to 3/21 between 0 and 23 @1
Calm for 32.78% of the time = 708 hours.
Each closed polyline shows frequency of 3.4% = 50 hours.

B. Workflow for Morphogenesis Based on Wind Environment

Input basic conditions, mainly including aboveground building area, number of floors, and layout type. The software generates a selection of spatial layouts based on wind environment, sunlight, and surrounding site conditions, with intuitive parameters available for comparison, selection, and modification [18]. After selecting a composite layout that meets expectations, the software generates more detailed body models based on debugging information. These meet the basic design volume relationships, and subsequent operations are carried out on this basis. By adjusting local building forms, such as partial overhead structures, guiding vents, and chamfering local shapes, real-time wind environment data can be viewed. Through numerical comparisons, the optimized building forms can be selected. A series of finely adjusted blocks can be imported into the wind environment analysis software for analysis. Based on the simulation results, targeted adjustments are made to the scheme to form the final plan [19].



Step 1
Open Rhino as the modeling software, launch Grasshopper, and load the relevant plug-ins.

Step 2
Input basic conditions, primarily including the aboveground construction area, number of floors, and layout type.

Step 3
After selecting a basic layout that meets expectations, the software generates a more detailed body model based on the debugging information.

Step 4: Adjust the local shape of the building, and select the more optimized building form through numerical comparison.

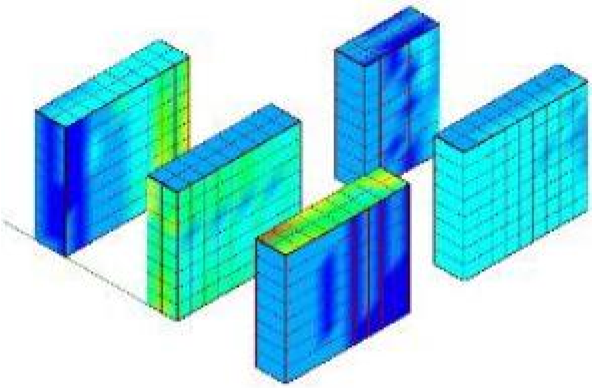


Figure 9: Simulation Calculation of Wind Speed on Building Facades (Summer Wind)

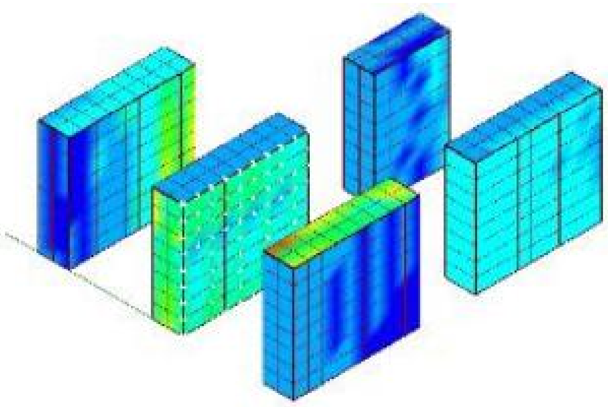


Figure 10: Units with Wind Speed Greater Than 0.5m/s on Retained Facades (Summer Wind)

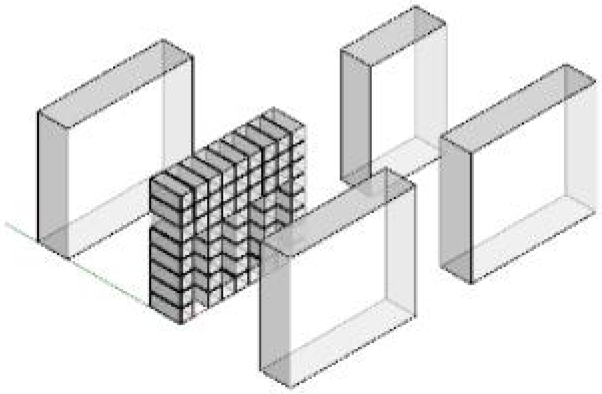


Figure 11: Retained Building Forms (Summer Wind)

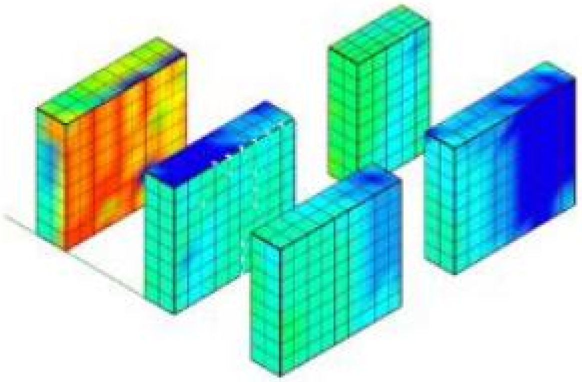


Figure 12: Units with Wind Speed Greater Than 0.5m/s on Retained Facades (Winter Wind)

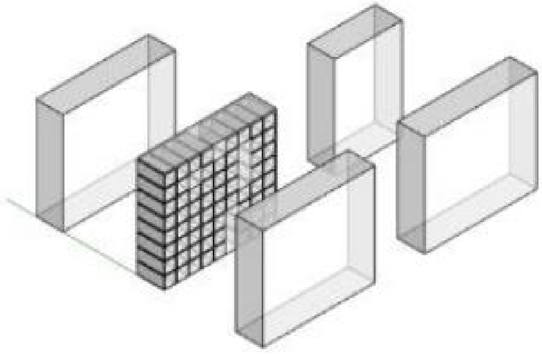


Figure 13: Retained Building Forms (Winter Wind)

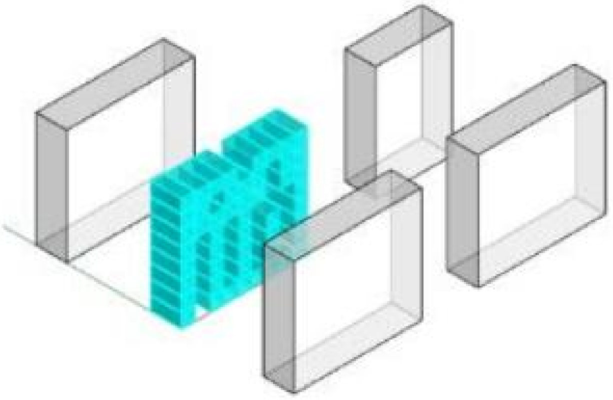


Figure 14: Intersection of Building Forms Obtained from Summer and Winter Winds

C. Achieved Effects of the Case Study

C.1: Establishing Continuous Airflow Pathways Within the Project Site

In the courtyard of the building complex, the design of the open space on the first floor focuses on connectivity with the surrounding green spaces and small activity areas to ensure that the service spaces throughout the area perform well in terms of airflow. This includes organically connecting the small open spaces with the adjacent roads while increasing the transparency rate of the first floor to allow natural ventilation to flow freely throughout the entire land area. In achieving this goal, the architect must carefully regulate the dimensions of the open spaces, including width, length, height, and relationship with the prevailing wind direction. In particular, small open spaces should maintain a smaller angle with the prevailing wind direction, which will help increase the air pressure difference between the front and back of the building clusters, thereby accelerating the exchange rate of air [20]. This design strategy plays a positive role in alleviating localized accumulation of haze. By meticulously planning the relationship between the building's open spaces and the surrounding environment, we not only improve air circulation but also create a more pleasant outdoor environment. This professional approach not only contributes to improving air quality but also enhances the sustainability and environmental quality of the entire area, demonstrating a highly specialized and systematic consideration of wind environment guidance. Therefore, the rational regulation of these open space layouts and wind direction relationships within the building courtyards is an important design strategy, providing strong support for the collaborative optimization of buildings and the environment.

C.2: The Layout of Building Forms with Height Variations Helps Improve the Vertical Distribution of Wind Fields

The first floor of the academy adopts an elevated structure, with the central area partially enclosed while retaining certain open spaces. The higher levels feature a design where the volume gradually decreases, creating a staggered form relationship throughout the building. This design strategy helps guide the airflow from the top downward to the lower levels and ground, effectively reducing the area of the wind shadow zone at the leeward side of high-rise buildings. When considering the dominant wind direction of the plot, we conducted an in-depth analysis to derive a rational three-dimensional building layout. This layout positions the building at an angle to the prevailing wind direction, thus reducing the occurrence of narrow channel effects and vortex zones. This means that the building better adapts to airflow, not only improving ventilation but also alleviating adverse impacts from wind on the structure.

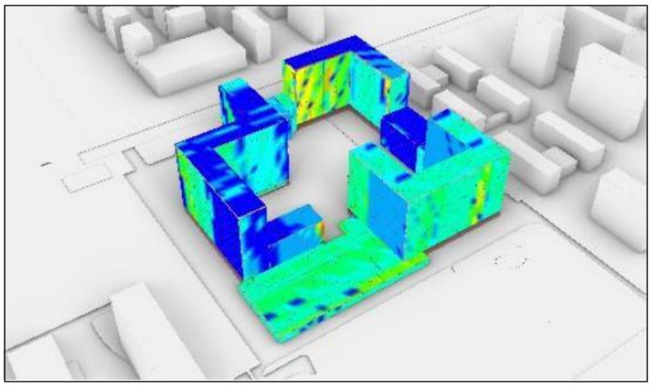


Figure 15: Impact of Overhead Layers on Wind Field

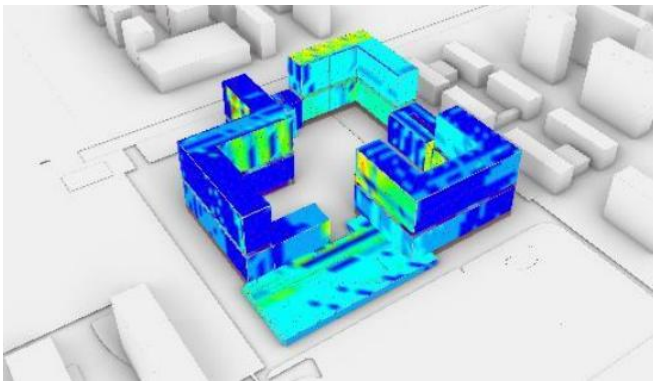


Figure 16: Impact of Adding Atriums on Wind Field

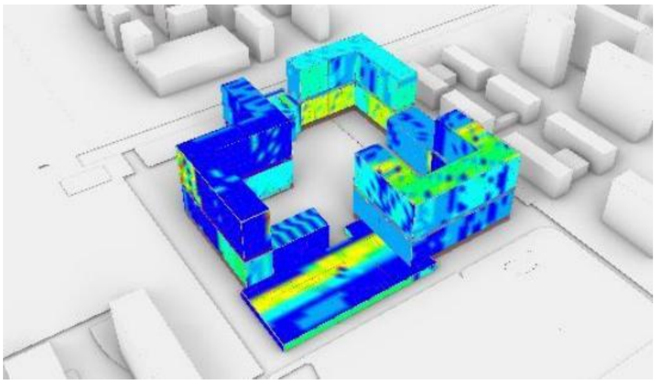


Figure 17: Impact of Middle-Level Overhead Structures on Wind Field

C.3: Considering the Influence of Mountainous Environment on Projects and Emphasizing Interconnectivity of Wind Path Spaces

Mountains like the Qinling Range significantly influence the dominant wind direction in Xi'an. In urban planning and architectural design, it is crucial to consider the impact of mountainous environments, particularly focusing on the interconnectivity of wind path spaces. By increasing the opening rate on the windward side of buildings, one can effectively improve their permeability, enhancing the street-level wind-thermal environment. Such strategies enable smoother airflow within cities, mitigating the obstruction caused by mountains, and providing more comfortable walking conditions for residents.

When considering the effects of mountainous environments, urban planners and architects should prioritize the interconnectedness of wind path spaces. Through rational layouts of streets, public spaces, and the positioning and height of buildings, one can break down the airflow barriers created by mountains, creating a more comfortable and livable urban setting. This not only aids in improving overall urban wind environment control but also enhances residents' quality of life, embodying the sustainability and adaptability of mountain city planning.

V. CONCLUSION AND OUTLOOK

From the perspective of urban micro-renewal, this research proposes and discusses a novel architectural form generation design method centered around wind environment control. It breaks away from traditional architectural design paradigms. Our method emphasizes the key role of interactive technology, integrating physical entities, data, and neural network algorithms, offering new possibilities for architectural design. This expands the application domain of environmental performance simulation tools and provides potential opportunities for shaping new design paradigms. We encourage the incorporation of big data collection methods based on physical experiments into performance-based generative design, transforming the architectural design process from a serialized mode to a more interdisciplinary cyclical process. This offers fresh prospects for future applications of artificial intelligence and multi-performance simulation tools in designing buildings based on specific design rules.

As art historian Kuhler once said, we should not merely replicate or vary past works but rather re-examine the relationship between material entities and free creation in an era of rapid technological advancement. This study's methodology and thought liberate architectural design from the constraints of digital tools, endowing it with greater innovation and potential. In the future, we will continue to trace the future from the past, redefining the significance of material entities and exploring the possibilities of physical tools in the intelligent age, promoting continuous progress and innovation in the field of architectural design.

REFERENCES

[1] Guo Fei, Li Peiyu. "Building Form Generation Strategy Based on Wind Environment". Journal of Housing Industry. 2016.07

[2] Zhang Tie, Zhou Leshi, Qu Yating. "Application of Wind Environment Simulation in the Optimization Process of Building Spatial Layout in Cold Regions - A Case Study of an Office Building Project in Shenyang". Journal of Building Energy Efficiency. 2020,48(08): 118-125+136

[3] Liu Chao, Li Zhuoxin, Chen Zhinin et al. "Based on Microclimate Simulation..."

[4] Guo Fei, Zhu Peisheng, Duan Dongwen et al. "High-density Urban Climate Assessment Methods and Applications". Journal of Western Human Settlements. 2015,30(06): 19-23. DOI:10.13791/j.cnki.hsfwest.20150605.

[5] Gao Maolin. "Research on the Method of Building Shape Rationalization Based on CFD Wind Environment Simulation and Comfort Evaluation". [D]. Jinan University, 2020.

[6] Yuan Feng, Lin Yuqiong. Research on the Method of Generating Architectural Group Form Based on Physical Wind Tunnel and Neural Network Algorithm [J]. Journal of Western Human Settlements, 2019, 34(1): 22-30.

[7] Sun Yanghong. Optimizing Thermal Comfort in Tall Atrium During Winter [D]. Shandong Jianzhu University, 2019.

[8] MORRIS I. The Measure of Civilization: How Social Development Decides the Fate of Nations [M]. New Jersey: Princeton University Press, 2013.

[9] Yuan Feng. From Diagrammatic Thinking to Digital Construction [M]. Shanghai: Tongji University Press, 2016.

[10] Xu Songyue, Qi Lin, Chao Jun, Sun Zonglie. Parametric Design Method of Building Skin Based on Wind Environment - A Case Study of Conceptual Design Scheme for Harbin E-14 Plot [J], Architecture Skills. 2015, 2.125-127.

[11] Hsiao Chunshuo, Liou Shuennren. Generating Architectural Envelope through Mathematica [C]. GA2008 11th Generative Art Conference. 2008, 349-254.

[12] CHEN T, HUANG M S, SONG K. A New Evaluation Criterion of Minibus Compartment Thermal Comfort Based on the CFD [J]. Applied Mechanics and Materials, 2013, 318(114-119)

[13] BLOCKEN B, VAN DER HOUT A, DEKKER J, et al. CFD simulation of wind flow over natural complex terrain: Case study with validation by field measurements for Ria de Ferrol, Galicia, Spain [J]. Journal of Wind Engineering and Industrial Aerodynamics, 2015, 147(43-57).

[14] YAFENG G, RUNMING Y, BAIZHAN L, et al. Field studies on the effect of built forms on urban wind environments [J]. Renewable energy, 2012, 46

[15] ROELOFSEN P, VINK P, VINK P, et al. Improvement of the Stolwijk model with regard to clothing, thermal sensation and skin temperature [J]. Work, 2016, 54(4): 1009-1024.

[16] Abed Al Waheed Hawila, Abdelatif Merabtine, Nadège Troussier. Numerical and experimental investigation on the thermal behaviour of the building integrating occupant thermal comfort [J]. 2020, 307

[17] Patrick Kastner, Timur Dogan. Eddy3D: A Toolkit for Decoupled Outdoor Thermal Comfort Simulations in Urban Areas [J], Building and Environment, 2022, Vol. 212.

[18] Wu Xiaoyi. Analysis of Natural Ventilation Status and Optimization Strategies of Teaching Buildings in Shenzhen University Town [D]; Harbin Institute of Technology, 2015.

[19] Liu Xiaodong, Li Yang, Qian Feng. Study on Ventilation Environment of Different Morphological Teaching Buildings [J]. Architecture Science, 2019, 35(10): 103-109.

[20] Huang Wenxiong. Simulation Research on Indoor Thermal Environment and Human Thermal Comfort of Air Conditioning [D]; Donghua University, 2017.

[21] Wang Yuhan, Qian Cheng. Analysis of the Impact of Building Wind Environment on Human Comfort [J]. Urban Architecture, 2019, 16(18): 115-6