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Study on the Coupling Mechanism of Spatial Form and Mesoscale Wind Environment in Coastal Cities Based on Multivariate Analysis: Methodologies and Frameworks

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Abstract. This paper studies in a parallel way the urban spatial form and wind environment by interdisciplinary, multi-dimensional and various comparative analysis based on advanced theories in the process of on-site collection of test data, computer-based simulation processing and laboratory verification using the best case-by-case analysis methods from the multivariate analysis technology, and finally returns to the study of how to apply the research achievements to the social community to benefit the public.

Introduction

With the development of modern city, the urban wind environment has become significantly different from the wind environment in the context of the mega-geography, forming the unique climatic characteristics of the wind environment in urban areas. Due to the particularity of the urban wind environment, all the activities in the urban environment and all the buildings built-in the urban environment should take into account the effects of these winds. This issue has aroused extensive attention in urban planning, architectural design, meteorology and other fields, which were studied early in the beginning of the 20th century. China's urban wind environment researchers also conducted a lot of observation and research on the urban wind field after 1970s.

China's urbanization process not only reduces the urban wind speed, but also makes the urban wind characteristics changed. With the development of the city, the significant increase and vertical expansion of buildings, the surface roughness changed greatly, causing the local atmosphere to change, and the turbulence of the airflow and the vortex caused by the blockage of the building were greatly increased. This indicates that the urban spatial form has great impact on the urban wind environment. Therefore, the relationship between urban spatial form and urban wind environment has gradually become a new concern of urban wind environment research.

In the previous study on the relationship between urban spatial form and urban wind environment, the quantitative index of urban spatial form cannot comprehensively outline the urban spatial morphology, and the relationship between quantitative index system and wind environment needs further study. Therefore, this study builds up the evaluation index system of urban spatial form and urban wind environment by classifying the study of the spatial form and wind environment of coastal cities of China and abroad, and conducts data extraction by CFD numerical simulation and correlation and data analysis collation and analysis by multivariate analysis method to reveal the quantitative relationship between the spatial form and the underlying surface wind environment. Through the exploration of the urban spatial form and the quantitative description index system of urban wind environment, it can provide a more accurate entry point and direction for the future research, and provide a quantifiable index and theoretical basis for the actual coastal city planning.

Research method

Case study and its data collection and processing. The mesoscale wind environment and the quantitative study of the spatial form need to have a specific urban case as the object of study. The city to be taken as an object of case study must be a typical example to represent the most coastal cities or key cities of China in terms of characteristics of urban spatial form and coastal urban wind environment, and is possible to provide sufficient and accessible data, pictures and other information about its spatial form. Our previous study "A Multi-variable-based Study of Xiamen Digital City's Near-surface Wind Environment" (He Ke, SAKAI Takeru, project No. GDT20163600002, 2016 / 01-2018 / 12), and " A Multi-variable-based Digital Analysis of the Spatial Form of the Ancient City Walls in Southeastern China" (He Ke, Wang Chengkang et al., Project No. 51408118, 2015 / 01-2017 / 12) have made some progress in the selection of the cases of the quantitative study of urban spatial form and wind environment in some coastal cities of China, and provided some information basis for access, transform and screening of data in the process of the study.

Abstract extraction and multivariate analysis. On the one hand, the analysis of the operation object of urban spatial form generally involves the abstraction of the key block and the street patterns into a model, and presents it with selected typical parameters. On the other hand, the data of the urban air surface environment with the greatest impact on the whole wind environment are extracted, and the multivariate analysis method of the large amount of wind environment is sorted out and analyzed to come out with the quantitative relationship between each spatial form and the surface wind environment (such as the relationship diagram, function, formula, etc.). Multivariate analysis technology is the application of statistical and analytical techniques for the processing of complex variables since the introduction of the collaboration with Professor SAKAI Takeru in Japan since 2014. In the face of this more complex parametric system, we will continue to expand the breadth and depth of this technology application.

CFD simulation method. CFD software is used to conduct wind environment simulation of the urban blocks and the defined abstract model to obtain the wind environment images and data for result analysis. Chen Qiuhua, the main participant of the research group, as the deputy director of the sea west wind engineering research center, has done some basic research of CFD simulation, which is one of the important contributions to this research.

The method of wind tunnel experiment. Put the scaled terrain and geomorphology in the wind tunnel for testing. The model design should ensure the original topographic features, and the wind tunnel experiment should ensure that the wind profile, turbulence degree, roughness and turbulence integral scale meet the requirements. The Haixi Wind Engineering Experimental Center lately built by the Xiamen Institute of Technology where the author serves as a part-time employee has a set of advanced multi-functional boundary layer wind tunnel equipment with a profile length of 75m, width of 35m, using a single reflux, tandem closed double test section type. It can achieve ultra-low speed steady-state wind field control as low as 0.5m / s. This has provided a good experimental physical condition for the study.

Technical route

In order to simplify the complex problem, for the flexibility, mobility and expandable space of the system, we adopted the modular research combination, which is divided into coastal city spatial form module, coastal city mesoscale wind environment module, multivariable analysis module, wind tunnel test module and the results of the transformation of the five modules. All the modules are relatively independent and complementary to be put together to form a complete research system. (Fig. 1)

Coastal city spatial form module. Urban spatial form is one of the two main foundations of this study. Based on the particularity and complexity of the coastal city spatial form and our accumulation of the previous part, which focuses on how to quantify the urban spatial form and use it for the multivariate analysis after screening and classification in the following four steps:

- The basic theory of urban spatial form and the study of its cutting-edge technology.
- Spatial and temporal positioning of coastal space in the coastal area.
- Virtual modeling of the urban spatial form scenario and 3D printing of the physical model
- Quantitative data extraction, collection, classification and collation of coastal city spatial form.

Coastal city mesoscale wind environment module. The coastal city's mesoscale wind environment is the second basis of this study. Based on the complexity of the wind environment itself and the demand for both wind resistance and ventilation in the coastal city environment, as well as prevention and control of urban heat island and air pollution, considering the research foundation, the research conditions, the research efficiency and the feasibility, we have selected the underlying bedding layer which has the greatest influence on the urban wind environment as the object to study in four steps as follows:

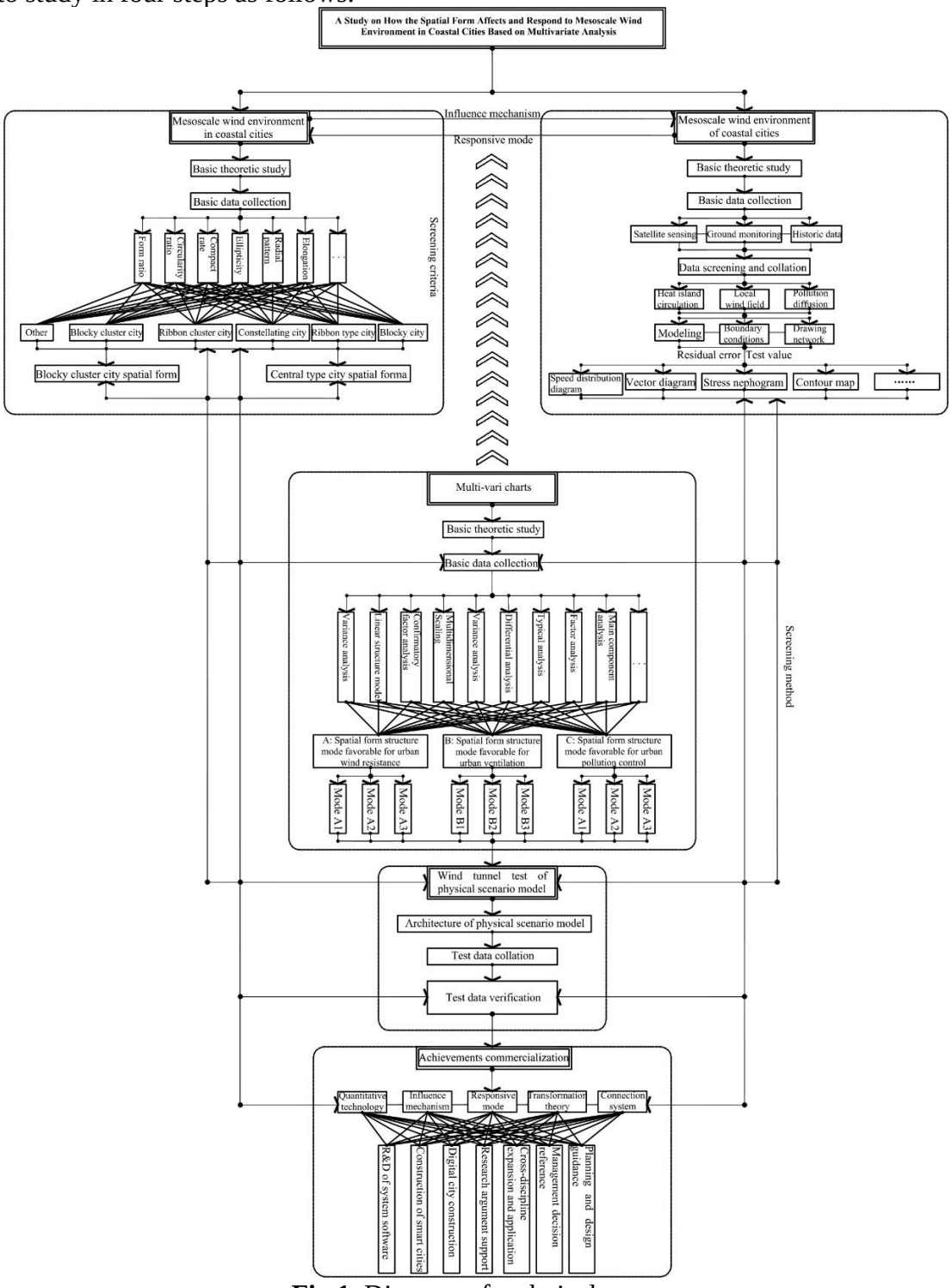

Fig 1. Diagram of technical route

- The basic theory of coastal urban wind environment and the study of its cutting-edge technology
- Basic data collection of coastal city mesoscale wind environment
- Computer simulation of coastal city mesoscale wind environment
- Experimental study of wind tunnel in the urban mesoscale wind environment and its data application

Multivariate analysis module. Multivariate analysis technology is one of the innovative applications of this research, and has been studied in recent years by us since the introduction of it by Professor SAKAI Takeru of Japan. This technology can realize the effective digital connection between the urban spatial form and the coastal city to get a more accurate, objective and effective conclusion. The study was conducted in following three steps:

- Basic theory of multivariate analysis and study of its cutting-edge technology
- Multivariate analysis techniques for the whole process of quantitative research
- Spatial pattern setting for the whole process of quantitative research

Experimental verification module. Wind tunnel laboratory is a strong physical support to the research. According to the set of scenarios, a solid model for wind tunnel test was built, and the experimental data and demonstration results and field measurements were compared to verify them. The difference interval was fed back to the previous quantization process or analysis process.

- Experimental test on the data of the mechanism of the spatial form affecting the mesoscale wind environment in coastal cities.
- Experimental test on the data of the strategy of the spatial form responding to the mesoscale wind environment in coastal cities.
- Feedback difference interval to the previous quantitative process or analysis process.
- Experimental test on adequacy, completeness, rationality and operability of the parametric system.

Achievement commercialization module. Research is conducted for learning, and learning is used for application. Part of achievement commercialization is intended to reduce the research achievements to practice for the benefit of the social community, which is conducted in four steps as follows:

- Transforming research achievements into efficient systems or software to serve the smart city, digital city construction, etc.
- Applying research achievements to other scientific and technological research
- Exploring the extension of space
- Applying the research achievements to the reference for the management decision-making and guidance for planning and design.

Conclusions

The innovative method and technology for the study of urban wind environment based on quantitative analysis. The construction of modern cities that carry the load of human activities, resource consumption and waste will greatly change the urban climate, and even result in uncomfortable and unsanitary living environment to bring direct impact on the quality of life of urban residents and worsen urban ventilation, lighting, heat island effect, air pollution, poor sanitation and other problems. With the progress of urbanization in China, the construction of modern cities has improved the living standard, but it will also increase the environmental burden, resulting in poor urban ventilation, heat island effect, air pollution, light pollution and other problems, of which the city ventilation as the daily necessity of urban residents has become an urgent problem to be solved in urban development program.

The application of multivariate analysis to the analysis of urban spatial morphology is a continued theoretic and practical combination. With the dramatic increase in personal computer processing capacity over the past decade, the windowing of statistical software, the complicated new method and the verification research have been paid more and more attention. Therefore, the

methodology of multivariate analysis has developed quite vigorously. At present, various multivariate analysis methods have been widely used by the enterprises, government agencies and universities in the study of various disciplines. Based on the theory of multivariate analysis, urban spatial form analysis and the theory of urban wind environment, this study, by reference to the Japanese experience and achievements in multivariate analysis theory applied in the analysis of urban spatial form, establishes a multi-dimensional city information model suitable for China's coastal cities to use multivariate analysis theory to the digital analysis of urban spatial form.

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