PERFORMANCE-BASED SIMULATION FOR THE PLANNING AND DESIGN OF HYPER DENSE URBAN HABITATION

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Abstract. The rapid development of the economy and urbanization create great pressure on population of Hong Kong, China and other developing countries. This not only brings great changes on the form and style of the urban sphere, but also, challenges to the natural environment and resources to support urban habitation. Regarding the process of urbanization, the development of the housing industry becomes the focus to resolve the need of materialization for urban living. For this reason, from time to time, technical and economical considerations are always prior to the significance of human settlement environment, humanity, and sustainable development. Considering the deficiency in urban human settlements environment, especially in responsiveness to the natural environment. Information technology (IT) undoubtedly can help to promote and assess the design and planning quality in both environmental and regional microenvironment aspects. A research project-Environmental Responsible Architecture and Urban Design (ERAU)-is established to support urban scale planning, information processing, and computer-aided performance evaluation on both micro and macro building design and planning efficiency.

1. Introduction

The rapid development of the economy and urbanization create great pressure on population of Hong Kong, China and other developing countries. This not only brings great changes on the form and style of the urban sphere, but also, challenges to the natural environment and resources to support urban habitation. Regarding the process of urbanization, the development of the housing industry becomes the focus to resolve the need of materialization for urban living. For this reason, from time to time, technical and economical considerations are
always prior to the significance of human settlement environment, humanity, and sustainable development. The "hardware" approach is often chosen by the government agencies as the major means and is given high priority in its implementation process to satisfy the social condition. Based on the measurement of the "hardware", several index tables have been established to guide the development such as average living area per person, construction cost per square footage, and open space per resident. Influenced by the development pattern of western cities, the mode and theory of planning and design follow logical and feature-oriented approach. This helps greatly in many aspects of urban development, for example, the transportation framework establishment, infrastructure planning, urban habitation development, land use control, and density regulation. Yet, at the same time, it also posts new challenges for maintaining a stratified relationship between building complexes and their surrounding environment in terms of functional and spatial configuration.

Quality urban human settlements environment should not only focus on the feature-oriented "hardware" development, but also establish the integration of human and natural environment according to its unique spatial context and urban landscape. The comprehensive design and planning process of unique urban landscape could give residents more direct impact to the sensation than the abstract human settlement environment as well as the in-depth psychological construction mode. For years, the livability and efficiency of the human settlement environment of Hong Kong and China cities have been left ambiguous by the planning, design, construction, property management and real estate sectors. There is no precise and useful control over the performance of the designed and planned urban environment. Especially there is a lack of qualitative tools for design evaluation. Meanwhile, during the early stage of design development, there is insufficient procedure and tools to easily assess the impact to the urban landscape caused by the settle pattern.

Considering the deficiency in urban human settlements environment, especially in responsiveness to the natural environment, information technology (IT) undoubtedly can help to promote and assess the design and planning quality in both environmental and regional microenvironment aspects. Technologically, IT provides a dynamic process for design, management, and supervision of the living environment construction. It enables immediate scientific judgment and response information. A research project - Environmental Responsible Architecture and Urban Design (ERAU) - is established to support urban scale planning, information processing, and computer-aided performance evaluation on both micro and macro building design and planning efficiency. The work is to develop the predictability and descriptiveness of performance evaluation tools, to investigate the methodology to integrate these tools into early design stage, and to reduce the faults in planning and design due to the ignorance of building performance.

Five major research components which have complex inter-relationships are included in ERAU: a. urban visual sustainability; b. urban wind environment
and natural ventilation; c. thermal comfort and building energy efficiency; d. natural lighting for urban space and architecture; and e. acoustic quality for urban planning and building design. In this paper, research works from above research components are selected to demonstrate the mechanism and discuss the outcomes. Research works related to urban visual sustainability is discussed in another CAADRIA 2002 paper, GIS-based visual perception assessment of mountain skyline: Case Study of Jinzhishan Hill and the Building Layout of an Adjacent Site Planning Project by Mr. Jie HE & Prof. Jin-yeu TSOU.

2. Urban Wind Environment and Natural Ventilation

Wind environment in building complex and indoor ventilation is the key elements of physical comfort. Moreover, the efficiency of ventilation is directly related to the energy conservation of building. Therefore, this has become one of the major direction of “Green architecture” in the sustainable development. Maintaining smooth ventilation and avoiding returned exhausted fume into the indoor environment, maintaining fresh air of suitable air speed in outdoor environment, and reduce pollution, are the basic consideration in the planning and design of architectural wind environment. For a big country like China, different regions have completely different considerations of wind environment. The different local geographic conditions, insulation and cooling requirements become great challenge to the architectural wind environment design in China.

For many years, the research team has focused on the application of Computational Fluid Dynamics (CFD) in architectural design of different scale. We mainly use computational fluid dynamic on wind load on the building elevation, wind environment at the building complex and the indoor ventilation for computer simulation. Combing with the visualization technology, information of wind pressure and air flow pattern can be provided to the designers at the early stage of design. In this case, designers can improve the physical environment before too much commitment has been made for a design scheme. Compared with the traditional method of wind tunnel testing and field measurement, computational fluid dynamic does not only save time and cost, but also has many advantages in technology (Tsou, 2001).

2.1. AIR MOVEMENT AND REGIONAL URBAN WIND EFFECT OF “SKY GARDEN”

Collaborating with HKSAR Buildings Department, research team applies CFD technology to investigate the urban wind phenomenon associated with the “green features” suggested by the government environmental design guideline. These features include wind catcher, sky garden, podium garden, and wing walls etc. Different design configurations have been identified as the key factor to investigate, and understand the effectiveness of the sky garden, and, establishing...
the basic rationale to assess the performance are the main objectives. In our case study, several high-rise residential blocks located at the HK Island have been chosen as the basic configuration to carry out the test. CFD models have been built for investigating the configurations such as minimum height, the effectiveness to balance the regional wind condition, safety considerations under extreme wind speed, the location of the garden, and contribution on thermal comfort. Air speed chart and the air movement diagram are generated to allow building controllers and architects to draw major hypothesis for giving rationale on the sky garden design. (Figure 1).

Figure 1. Left: Wind environment at building complex; Right: The effect of building form on wind environment at pedestrian level

2.2. NATURAL VENTILATION STUDY FOR HIGH-RISE RESIDENTIAL BLOCKS

Cooperating with the Kenzo Tange & Associates, we evaluated the physical environmental condition of the project, and made suggestions regarding natural ventilation, daylighting, and noise impact. We also made use of this integrated analysis to design an environmental friendly underground car park. The wind environment of this project covered different scale of building design issues such as extreme air movement caused by the building cluster and geometry, the space between the building blocks, opening location for natural ventilation, wing wall design associated with the openings, and the location of major inlets/ outlets. Based on different kinds of climatic conditions, CFD models are built to simulate the wind environment and indoor air movement. The air flow patterns surrounding the building complex and at the activity zones are analyzed to identify potential problems. For example, the wind noise caused by the "near gap" between buildings and the re-entry problem of the kitchen exhaust are two major areas for improving the design after reviewing the simulation outcomes (Figure 2). In the environmentally friendly underground car park design, we also applied the CFD as design exploration tools to investigate the integration of "wind scoope", "wind catcher", and "chimney effect" into an underground carpark in order to maintain the required air exchange rate using natural ventilation (Figure 3).
3. Daylighting for Buildings and Open Space Environment

Through daylighting simulation, the impact of daylight on the physical environment can be studied. This includes impact of direct sunlight, diffused light and reflection from other objects in the environment. Daylighting simulation results provide supplement information to designers to consider design issues such as daylight factor, illuminance, solar radiation, and visual comfort. Since providing proper shading and reducing radiation gain are two main concerns related to the energy conservation strategy for sub-tropical climate, the simulation outcomes with graphical representation enhance the efficiency of the "what-if" analysis process in planning and design of building complex. Because the luminance and glare could affect human comfort at both physical and psychological level, the research team also works with architects to investigate design strategies to improve this important quality factor. Other daylight performance issues been investigated by the research group include the location and adjacency of building groups, site layout, inter-block shading strategies, and solar access.

3.1. DAYLIGHTING ANALYSIS FOR HIGH-RISE RESIDENTIAL BLOCKS

In the daylighting analysis of this project, we simulated the inter-block shading environment in different seasons. Besides, we simulated the condition of radiation gain on building elevations in different seasons for energy saving design and the consideration of building enclosure (Figure 4). Moreover, we evaluated the daylighting environment of different activity zones for efficient planning and design of the outdoor activities and facilities, which in return, increase the design quality and comfortability for high density urban settlement.
4. Urban Noise Simulation for Room Acoustics

In these projects, we now are focusing on the simulation and the analysis of the acoustic environment at two levels: urban noise and room acoustic. For the subtropical hyper-dense urban settlement, besides “Heat Island” phenomenon, “Sound Island” also becomes a major concern of the planning of our future urban environment. Urban noise includes traffic noise, construction noise and neighboring activities. Noise could cause serious disturbances to comfortable living, especially in the dense living environment with very limited living area available to individuals. Psychologically, urban noise and room noise could seriously affect people's perception regarding the crowdness and adaptation of the space usage. Considering Hong Kong's unique habitation pattern, there is an urgent need to apply good practice in urban planning and building design to ensure the acoustic quality for liveability purpose. Yet, improper planning due to the rapid urban development has increased the acoustic disturbance to the residential environment.

With acoustic simulation and scientifically visualization, designers can have a thorough understanding of the acoustic environment, and hence assisting effective building design and planning strategies to improve the acoustic quality of the living environment. In the acoustic simulation, we use Raynoise, which, is based on geometrical acoustics that ‘sound waves’ are considered as ‘sound rays’. The algorithms Mirror Image Source Method (MISM) and Ray Tracing Method (RTM) are employed which are effective in providing precise noise source information for architectural acoustics (Kang, Tsou and Lam, 2000).

4.1. NOISE STUDY FOR HIGH-RISE RESIDENTIAL BLOCKS

Since the building site is adjacent to major traffic route of the city, the road noise has great impact on the residential blocks (Figure 5). We examined the effectiveness of different architectural approaches to reduce the noise impact, and the protection of the central courtyard from the unpleasant road noise (Figure 6). The location and effectiveness of different types of noise barrier were tested, and master site plan was revised according to the information given by the simulation. Sound pressure level (SPL) and reverberation time of the urban noise are two main components which cause discomfort, and the research team focused on the simulation of SPL in the urban context. Owing to the building configuration and materials adopted by Hong Kong high-density
settlement, special attention has been given to the treatment of low frequency noise. The low frequency noise as other research shown will have much greater impact on elderly and children as they spend most of their time in their flats. The hearing system of children is sensitive to the damage caused by the exposure to low frequency noise, and elderly will have difficulty to recognize the speech when the background low frequency noise level is high. We also consider the sound pressure level distribution of the open space in different frequencies to provide a base for architects to plan for layout and different facilities.

5. Conclusions

With the increasing living quality, comfortability and responsiveness to the natural environment will become the major evaluation criteria for assessing the development of high-density urban habitation. The studies and applications investigated are not only for individual projects or specific technology development, but also for providing an integrated mode that supports environmental planning and design for sustainable development at humanity level. We hope that through information collection, information generation, information analysis and information visualization, we can support intelligent design, and increase the efficiency and liability of urban planning and the architectural design.

Meanwhile, there are many issues that need users' attention or further research according to the experience received from the project implementation process:

a. Extensive background knowledge is required to set up the correct parameters to generate meaningful simulation outcomes. For example, it is not an easy task to detect the mistake embedded in a CFD simulation and determine the cause of the error.

b. For maximizing the effectiveness of the use of simulation tools described in the paper, multidisciplinary collaboration is needed to interpret the outcomes and to develop alternative approaches.

c. In order to benefit from the scientific simulation process, planners, designers, or engineers should not merely treat it as a kind of post-design
evaluation activity, but consider the process as another mean of design innovation generation.
d. Since there is no "true" exchangeable design model data format, valuable time could be easily wasted by tedious works related to the model preparation and data conversion. Defining proper level of details for simulation and establishing design information management structure are two important considerations before carrying out simulation processes.
e. Overlaying different kinds of building design/performance information provides designers and planners further opportunities to evaluate their design decisions, therefore further research has been initiated to integrate the VR system and rapid prototyping system to simultaneously represent geometric design information and non-geometric building performance information.

References


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