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APPLICATION OF COMPUTER VISUALIZATION AND MATHEMATICAL MODELING TECHNIQUES IN THE DEVELOPMENT OF PLANNING CONTROLS DESIGNED TO PROTECT THERMAL COMFORT FOR PEDESTRIANS

by

Peter Bosselmann

ABSTRACT

This paper describes a new procedure to predict thermal comfort of people in outdoor places. The procedure is based upon a combination of experimental techniques, including wind-tunnel studies, mathematical modeling of the human thermo-regulatory system, accurate three-dimensional computer modeling of an urban environment, sun access studies, and realistic eyelevel computer simulation techniques. The paper describes the application of this methodology in urban design studies for the Cities of Toronto, San Francisco, and New York.

These studies have resulted in new building height and bulk regulations in San Francisco. Similar revisions are currently being considered in Toronto and New York.

Sun, Wind, and Scale in Urban Design

The form of cities emerges over time and is shaped by decisions about the construction and demolition of physical structures. Although these decisions are made without apparent connections, the form of cities emerges in predictable ways. The result is an urban form generated through a system of rules which forms a collective understanding about the design of cities. At its most basic level, this understanding supports a social system in which things are encouraged or discouraged through essentially social means, ranging from legal sanctions to the most subtle incentives.

One such rule is the right to light and air in city streets and open spaces. Limits on the height and bulk of buildings have existed as a legal embodiment of good neighborliness in order to assist public health and comfort. In fact, rules on height and bulk became the basis for zoning ordinances in the United States and elsewhere.

Sun and Air for New York Streets

In North America, the first study that led up to this subject was conducted in 1913 by the Commission on Heights of Buildings of New York City. The commission was an investigating body appointed by the Board of Estimate and Apportionment to study how skyscrapers affect the safety and health of the community. If the commission discovered an effect, it was to indicate what regulation could be lawfully adopted to bring improvement. When the committee was formed in the beginning of 1913, any office or hotel structure in New York City could cover an entire site, rise to any height, and maintain the lot dimensions at the highest story. Darkened streets and buildings were found to result from shadows. The Commission recommended that building heights and use should be regulated in the interest of public health and safety. The report resulted in a bill amending the city charter to introduce height and use districts under the provisions of the Board of Estimate and Apportionment. The law has been in operation since it was passed on 25 July 1916. The charter amendment came at a time when districts were expanding rapidly on the Upper East and the Upper West sides of Manhattan. The new height rules have given these districts and others a very distinctive form and character.

Height Limits in Paris

The Commission that framed the New York City charter amendment had made a careful study of building regulations in European cities. In Paris, for example, the King's declaration on Building Lines and Window Openings, dated 10 April 1783, was soon followed by an ordinance on 25 August 1784, defining the major principles of regulating architecture. These principles set a cornice line, slope of roof, and determined a facade's height as a function of the street's width. On

streets between 9.75 and 20 meters in width, the maximum height was fixed to 17.54 meters with roof sloping upwards at 45 degrees. In the hundred and fifty years following, the height limits were somewhat modified, in 1869, 1884, and again in 1902.

The use of the mansard roofs along most streets built during the Hausmann period strongly characterized the skyline of Paris after 1884. When the commissioners from New York examined the 1902 revisions to the Parisian building laws, they found that the height limits maintained the height of the street facade at 18 meters (the earlier limits had been 17.54 meters in 1784), but increased the total allowable height to 30 meters.

In Paris, situated at 49 degrees north latitude, a 45-degree slope of a roof would allow sunlight to reach into twenty-meter-wide north-south streets between 11:00 AM and 1:00 PM from April 2 to September 10. While the streets have more sunlight hours during the summer, most times of year and most times of day, the angles of the sun are lower. In New York City, located further south at 41 degrees north latitude, the angle of the sun exceeds 45 degrees more frequently during daylight hours in the course of the year, giving sun to 20-meter-wide streets, if 20-meter-wide streets were to run in the north-south direction, which they do not. Indeed, the setting of building heights according to sun angles appears somewhat arbitrary, given the various widths of streets, their orientation, and the location of a city with regard to the position of the sun and climatic zone.

Sun, Wind, and Comfort

Sun

Although the relationships between the overall form of a city and its climate can be intuitively understood, it is generally not possible to use intuition for predicting how specific future buildings will affect climatic conditions. Also, no mathematical model exists that can predict the effects of proposed structures on the comfort of those who walk along sidewalks or use public open spaces. A combination of experimental and computational techniques is necessary to make such predictions. For example, the amount of shadow a future building will cast on sidewalks and open spaces can be

measured by placing scale models into an artificial sky-laboratory where the sun is represented by a parallel-beam light source. The light source can be adjusted to represent the altitude and direction of the sun at any time. The extent of the shadows over selected times of the year is then measured inside the scale model. Sun-and-shadow analysis can also be performed by computer using a three-dimensional data file of all building, street, and open-space dimensions, combined with software for shadow-casting, shadow-accounting, and modeling of proposed buildings.

Wind

Similarly, in most complex cases, the airflow around buildings must be measured against a scale model of existing physical conditions placed in a boundary-layer-simulating wind tunnel. By inserting models of proposed or potential future development in the tunnel, accurate measurements of street-level wind velocity, direction, and turbulence can be obtained. Building-induced wind phenomena can be obtained through comparing measurements under existing conditions with measurements of changed conditions.

Comfort Modeling

The measurements of wind and sun or shadow conditions provide two of the six key variables that affect human comfort. Solar radiation provides warmth for the human thermo-regulatory system. Two other climate variables, humidity and air temperature, also affect thermal comfort. Values for these are usually obtained from weather records. In addition, informed assumptions have to be made about the activity levels of people and the amount of clothing worn. In recent years, researchers have attempted to establish computer modeling procedures that predict the combined effect of these six comfort-influencing variables. Although such techniques show promise and work reasonably well for predicting comfort conditions in indoor environments, they are still unpredictable with regard to climatic conditions outdoors. They may be used, however, to predict relative spatial and temporal comfort differences from alternative development scenarios.

It is possible, using the above methods, to make informed decisions about the effect of future zoning and planning controls on comfort conditions. In recent years, considerable experience has been gained in the implementation of environmental comfort policies, through testing proposed developments against specific performance criteria, or in the setting of zoning standards.

Daylight Access

Cities in the process of reviewing their master plan on built form criteria and environmental quality criteria can make use of a methodology that is based upon an understanding of the human thermo-regulatory system. In recent years, a number of North American cities have introduced policies that value sunlight and protect street environments from adverse wind conditions. With its 1982 Midtown Development Controls, New York City reintroduced the 1916 standards for preserving daylight and openness of street canyons to the sky. The revised planning standards in New York compare light conditions along avenues and streets of Manhattan under the historic 1916 district controls to conditions expected under new controls. Building forms and setbacks are calculated for anticipated light levels and a proposed Midtown building meets the standard if it permits a specified amount of daylight to reach the street level. However, the amount of daylight required at street level is not based on a criterion of human comfort or acceptable light.

Sun Access Standards

In a 1983 San Francisco study, the Berkeley Simulation Laboratory developed standards for sun access to downtown streets and open spaces. The sun-access controls set limits to the height of buildings in the vicinity of open spaces, and along streets that are actively used by pedestrians. These new height limits were based on modeling studies. They indicated that people walking or sitting would generally be comfortable in San Francisco, if they were in the sun. In response to the study, in 1984 the citizens of San Francisco voted to amend the city charter with an ordinance that protects sunlight to city-owned parks and squares from one hour after sunrise to one hour before sunset for all months of the year.

Sun Access Computer System

The passage of the sunlight ordinance as an amendment to the San Francisco City Charter made it necessary to establish an accurate three-dimensional database of public open spaces and buildings in downtown San Francisco. Using photogrammetrics, the Berkeley team established datafiles of fourteen downtown open spaces and 1,100 downtown buildings at an accuracy of ± 0.3 feet for all horizontal and vertical input dimensions. (This accuracy ensures a shadow-casting accuracy of ± 5 feet.) The open spaces were represented as raster files with a grid dimension of one foot by one foot. The buildings are represented as vector files. The team developed new software for a computer system complete with a shadow-casting module, an editor to insert hypothetical buildings, and a grid editor to change the configuration of open spaces. The system is capable of displaying the three-dimensional built form and building shadows. A shadow-accounting module computes the duration and extent of shadow areas. The system is used primarily to verify sun and shadow predictions supplied by sponsors of proposed downtown development projects.

Wind Ordinance

The modeling studies that led to sunlight protection had demonstrated the need for a downtown wind code. Subjected to strong and frequent northwest wind, San Francisco's streets are windy and cold, especially during the summer when sunlight is frequently hidden by fog. The height and placing of buildings has a major effect on street-level wind velocities. In order to avoid adverse wind conditions, a wind ordinance was developed for downtown San Francisco. The San Francisco Downtown Plan (implemented by the Planning Commission in 1987) requires new buildings to be shaped or sited in such a manner that ground-level wind limits for seating (7 miles per hour) and pedestrian areas (11 miles per hour) are not exceeded more than 10 percent of daylight hours.

Model of the Human Thermoregulatory System

This year the Berkeley team is involved in the development of planning controls for the City of Toronto that integrate criteria for a comfortable microclimate on sidewalks and in public open spaces with existing urban design controls.

Toronto can be seen as an example for the following explanation and demonstration of how planning controls could be developed that are based upon considerations for a comfortable street environment. Toronto's climate is characterized by cold winters and hot and humid summers. When temperatures and humidity are high, people in Toronto benefit from shade and a light breeze. Tree-lined streets and shaded sidewalks provide comfortable conditions for pedestrians during the hot summer days. Streets that are open enough to allow a breeze to penetrate are more comfortable for pedestrians. The buoyancy-driven flow of air between shaded sidewalk areas and sunny building and street surfaces will add to the comfort of pedestrians during these times.

During the winter, when air temperatures are cold, direct sunlight will be beneficial, but generally the angles of the sun are too low to provide sufficient direct radiation. Only in wind-protected locations in direct sunlight would a warmly dressed person feel comfortable, and only if such a person would walk briskly. However, during the spring and fall seasons a person leisurely strolling will be comfortable if the sidewalk or open space is sunny and protected from the wind. The relationship of the local climate in Toronto to the six comfort variables, sun radiation, wind velocity, temperature, humidity, clothing, and activity, are shown in a bioclimatic chart.

In order to study the influence of buildings, streets, and open-space dimensions on wind and comfort, experiments were made at the Berkeley Simulation Laboratory using scale models suitable for wind tunnel studies of representative areas. They showed the existing conditions, plus two future scenarios, that illustrate development conditions under current planning controls as well as under controls modified in ways assumed to reduce undesirable wind and shadow effects. This second future scenario was constructed after a number of tests had been completed, including wind-tunnel tests measuring the velocity of wind flows at sidewalk level. In the absence of an

accurate database for Toronto, the shading effects were determined by placing the models under a parallel-beam light source that was manipulated to reflect the sun's altitude and bearing angle at varying times of the day and year. To gauge the combined effects of measured wind and shadow conditions on pedestrian comfort, wind tunnel and shadow data was fed into a computer model that simulates the human thermo-regulatory system. The model considers ambient temperature and humidity from a long-range weather record, and adds wind velocity and solar radiation from the scale model measurements. Finally, assumptions were made about activity level and the amount of clothing worn. The product of this model was a numerical ratio that expresses the percentage of time a particular place would be comfortable for outdoor users during daylight hours.

In all areas chosen for the Laboratory studies, the analyses showed that adverse wind conditions would be created given future development allowable under current planning controls. In general, such conditions can be avoided if the height and placement of future building volumes are modified. The combined wind effect and shading caused by future development under current planning controls would render sections of sidewalks, and to a lesser extent park space, uncomfortable during the spring and fall seasons. Uncomfortable conditions could be avoided by scaling building dimensions in a way that allows sunlight to reach open spaces and sidewalks.

The findings of the Laboratory studies suggest the need for planning legislation that controls adverse wind conditions caused by new construction. In addition, the study recommends a height limit to preserve sunlight to parks and open spaces in the central City area during those times of the day and year when sunlight is most needed for thermal comfort of pedestrians using such open spaces for recreation. Finally, the study suggests that similar height limits be established which guarantee a minimum of three hours of sunlight at midday on all streets in the Central City area where people stroll and shop, and five hours of sunlight on streets where people live.

The outcome of this work has been a set of recommendations that are now being considered for implementation in Toronto's 1991 official Plan. If implemented, they would over time have an effect on the microclimate of the city of Toronto, and on the forms of that city.

In order to visualize the effect of such comfort controls on the scale of building, The Berkeley Simulation Laboratory prepared realistic eye-level computer simulations comparing street views of existing conditions with conditions that would result from current planning controls and with conditions that would result from modified controls.

The new controls would encourage new building volumes to line streetfronts more tightly but remain lower, rarely more than 1.5 times the width of a street. They would reduce the height of towers in many places. Finally, they would encourage smaller building dimensions, not only in height but also in floorplan dimensions. They would produce building dimensions that would produce a more finely scaled urban environment.

Intuitively, the relationship of city form and climate has been well understood. The comfort prediction procedure described in this paper provides planning officials and designers with useful quantitative information on the effectiveness of various design strategies for providing comfort in outdoor spaces. The methodology has the potential of being a powerful urban design tool, and, if applied, can result in more effective development control by providing the means for evaluating proposed legislation and development.

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