Optimise Urban Daylight Design Using Computational Simulations

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Urban design is about providing an infrastructure for its inhabitants. An important consideration of design is to provide natural outdoor conditions that are pleasant and conductive to human activities. A well designed outdoor urban environment will also make the design of individual buildings within it easier. There are many design parameters, for example: Development Density, Plot ratio, Site Coverage, Skyline, Building to Space Ratio, Permeability, Building Shapes and so on. This paper reports a study based on „skylines“ as a design parameter, and how it affects daylight and natural ventilation provisions and performance. Experiments are conducted with physical models in artificial sky, as well as using computational lighting simulations. The study establishes that by varying the skylines of the city, the overall daylight performances could be improved when compared to a city with a uniform skyline - given the same density. The message of the paper is that: through better understanding and design, high density cities could be planned and optimised without losing the development efficacy of the land.

Keywords: *Daylight; parametric study; urban design; density.*

Introduction

With the increase of the world's population, many cities are facing the problem of designing and planning to meet the demand of their inhabitants. Enlarging the city's land boundary, building satellite towns, optimise land zone and usage, and constructing taller and closely packed buildings are some of the tactics used

For cities with limited land area, like Hong Kong, the option opens to planners and designers is limited. Finding ways to optimise land use and designing for higher density seem to be the only options. For example, Hong Kong, is a city of 7.5 millions inhabitants living on a collection of islands total 1000 square kilometers. Due to its hilly typography, only 25% of the land is built-up. Urban density is around 30,000 to 50,000 person per square kilometer. Take away the areas for roads, rails, utilities and open spaces, building sites end up with a development density of around 3000 person per hectare. This results in high rise buildings, some 40-80 storeys, built closely together. Designing and regulating the provision of adequate natural light and air is a difficult task. [Ng et al 2003]

Land use density could typically be controlled using plot ratio, site coverage, permissible building volume, maximum building height, street width vs. building height ratio, building profile and set back, and so on. In most countries, regulatory control of most of these are prescriptive and are stated and applied with little understanding of their performance implications. For example, in Hong Kong, the permissible plot ratio of a piece of land is artificially set between 5 to 10. It is not known how the rules were set in the first place. It is not known what environmental parameters and considerations gave rise to a certain plot ratio to be set for a certain site. It is also little known what is resulting. In short, one is following rules without logic, reason or rationality. Hence, it is almost impossible to deal intelligently under unusual circumstances, and to design appropriately.

How some of these planning and design parameters affect the environmental performance of the resulting buildings is a research question. This paper reports results of parametric studies based on building density, street width and building skylines. The study investigated the sensitively and magnitude of these 3 parameters on the environmental performance of daylight and naturally ventilation of buildings.

Background

Many scholars worldwide have conducted researches on parametric studies that lead to simple design guidelines. Many lasting design understanding and guidelines started with the use of results of parametric studies. For example, Givoni studied the use of wing walls for room air ventilation, this is now adopted by the Hong Kong Government for its new generation of performance based regulation [Givoni 1969] (Figure 1). Hawkes studied the relationship between block spacing and daylight performance which later led in a site planning guide in the UK [Hawkes 1970]; Baker studied the relationship

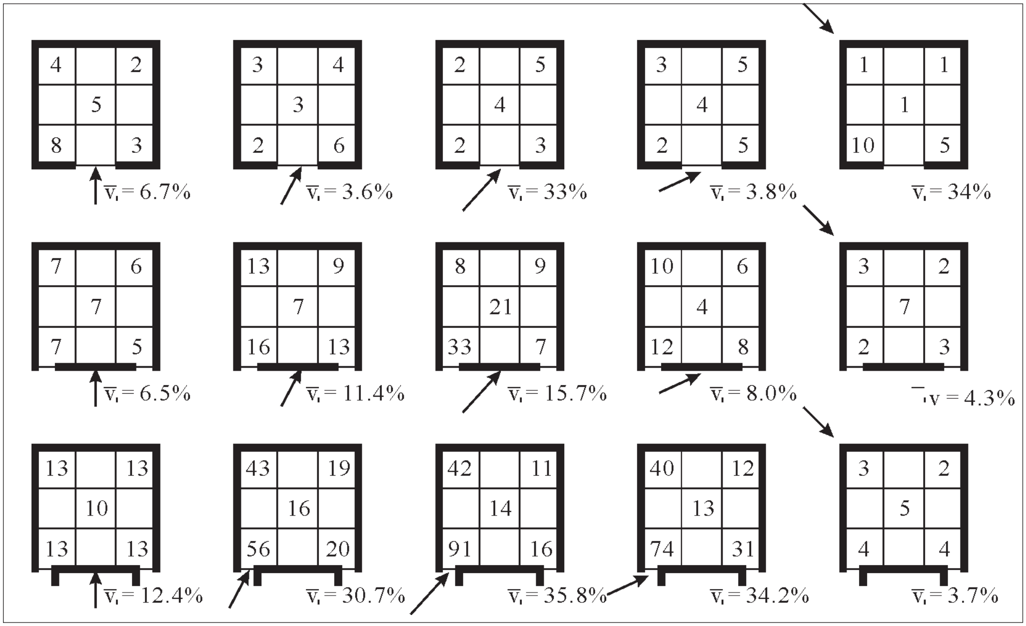


Figure 1
Givoni's parametric study of the effect of wing wall and air ventilation of internal spaces.

between window size and thermal-light energy performance which resulted in the development of the European LT method [Baker 2000];

Parametric approach is used in this study. The advantage of using parametric study in lieu of studies based on realistic circumstances is that issues could be isolated and simplified to reduce noise and error of results. It is also much easier to design experimentally. The disadvantage is that results obtained could not be directly and readily feed back to real problems. In most cases, results could only indicate the 'likely' sensitivity of the performance due to the parameter.

For this study, to mimic the conditions of an urban neighbourhood, a 5x5 base plate is used. The base plate has 25 buildings on a square array. The three parameters of density, street width and building skylines were investigated using a number of simplified scenarios. The 3 parameters and 3 variables give a permutation of 27 scenarios to be studied (Table 1). One such scenario is show in Figure below (Figure 2.) This is a 'random' layout with 'a density of 75 blocks', and with '3 different street width to building width' ratios.

For comparative reasons, the base case of 'uniform' height, with 'a density of 75 blocks', and with 'a street width to building width of 1:1' was regarded the base case. This is the kind of urban neighbourhood most likely to have resulted in Hong Kong given current regulations and control.

The Scientific Basis

Daylight performance of an interior space depends on the amount of light available to the vertical surface of the window pane. In turn, the amount of light receivable on the vertical surface of the building façade depends on a number of factors. Firstly, the amount of sky the façade 'sees', this is the sky factor. The sky factor, the amount of sky viewable in terms of solid angle, is corrected using the sky description of the locality to become the Sky Component (SC). Typically the CIE overcast sky description is used. This description depicts the sky condition of a dull cloudy day without direct sunlight. The amount of light available under this sky is azimuth independent. Many artificial skies and computational programme are built based on this sky type.

Secondly, in dense urban conditions, most available light is reflected light (ERC) of surrounding surfaces. It depends on the reflectivity of the surfaces, as well as how well these surfaces are illuminated directly in the first place. It has been calibrated in a previous

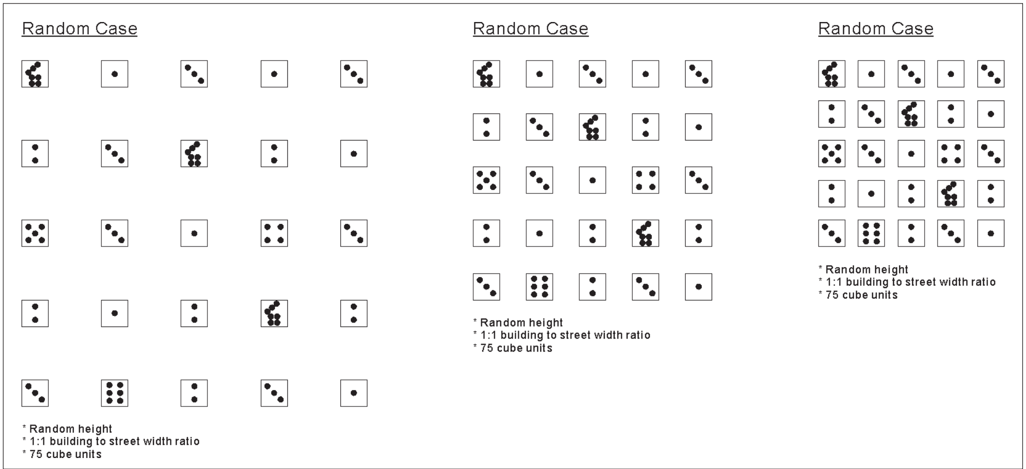


Figure 2
The diagrams show 3 scenarios tested.

Table 1
Scenarios of the study.

Parameters investigated	Variables used		
Density	2 blocks	3 blocks	4 blocks
Skyline	Uniform	Random	Stratum
Building to space ratio	2:1	1:1	1:2

study relating Sky Component, reflectance of surrounding surfaces, and vertical daylight factor of the building façade. [Ng 2003] Hence, knowing SC, the VDF could be computed easily. (Figure 3)

Methodology

Computational lighting simulation is used to conduct tests of the 27 scenarios. Lightscape has been selected. (Figure 4) The software has been calibrate to yield good results under heavily obstructed conditions [Ng 2001]. The geometry was modelled in FormZ solid modeller and exported .dxf into Lightscape. All surfaces are oriented and assigned reflectance of 0.2. Rendering with cloudy sky with sun illuminance set to 0, the results are picked using the Analysis Function of the programme. The illuminance of all four surfaces of all the blocks of the 5x5 grid on the base plate is recorded. Thus for a study with 75 blocks, 300 data points could be recorded.

Results

Results of the base case of 75 blocks and street width to building width of 1:1 is shown as an example in Figure 5 below. The uniform base case (Figure 5 left) illustrates that light levels generally fall into three distinct bands: top, middle and bottom. Roughly a third of the data points (100 data points) are in the low ranges roughly in the order of 8-9% Vertical Daylight Factor (VDF).

Results of the random and stratum scenarios illustrate that light performance spread out more and distribute along the x-axis. Summing the light performance of all the surfaces reveals that the median of base, random and stratum scenarios are 15.2%, 16.7% and 17.6% respectively. This means that on the whole light performance of stratum scenario is roughly 20% better that the base case.

Results of the 27 scenarios tested is summarised in Table 2. It is noted that in all cases light performance of stratum scenarios exceed the random scenarios, which in turn exceed the base scenarios. For example, in very high density conditions of 5x5x4, and a street width to building width ratio of 1:1, the performance of the stratum layout is around 30% better than the base case. That is to say, given the same design density, one design is better than the other by roughly a third.

Alternatively, examining the light performance of

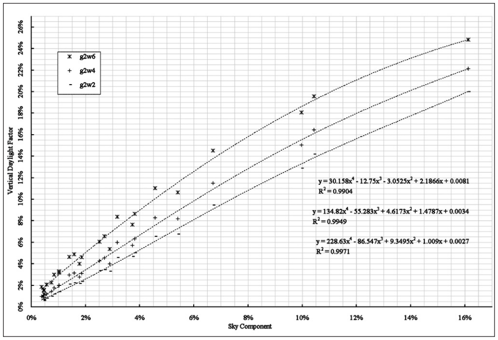


Figure 3
Sky Component (x axis) vs. Vertical Daylight Factor (y axis) under three different assumptions of reflectance of surrounding buildings (r=0.2 [bottom line], 0.4 and 0.6 [top line]).

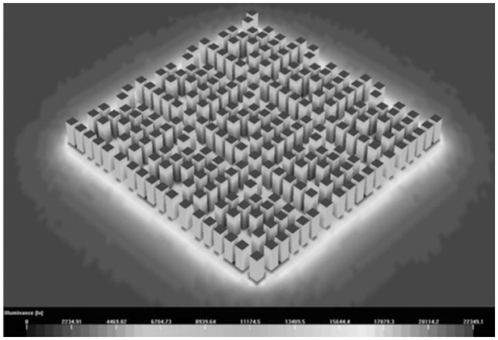


Figure 4
One of the 27 scenarios tested. Note that the base plate of 5x5 grid is surrounded by duplicates of itself to form an urban environment. Only data of the blocks within the base plate is used.

5x5x3 base and 5x5x4 stratum, the two set of data is very similar. That is to say, given a certain daylight performance requirements, one could build either 75 blocks all with the same building height, or 100 blocks with varying building heights. When plotting the 27 scenarios along the VDF y-axis, it is noted that, in general, light performance shift up from base, random to stratum. (Figure 6) The improvement is roughly 10 to 30%.

Discussion

Simple prescriptive based regulating methods, like the use of Rectangular Horizontal Plane (RHP) and maximum permissible heights in Hong Kong, will invariably lead to simple, but not optimised, solutions. Typically, this leads to buildings of similar heights. And it has been demonstrated that it yields sub-optimum results.

The study demonstrates scientifically that for natural lighting, better performance could be obtained by varying the skylines. (Figure 7) The improvement is around 20-30%. Thus, it is important to capitalise this by effecting design guides, building and planning regulations to encourage that to happen.

Further works

This study only identifies preliminarily the quantitative effects of 3 parameters. Further studies are needed to include additional scenarios and to further investigate the precise mathematical relationship between the parameters and performance. For example, if building skyline is an important pa-

	Street: Building	Base	Random	Stratum
5 x 5 x 2 blocks high	2:1	31.3	33.7	34.5
	1:1	20.2	22.5	23.2
	1:2	12.4	14.9	12.8
5 x 5 x 3 blocks high	2:1	**27.3**	27.5	29.1
	1:1	**15.2**	16.7	17.6
	1:2	**8.1**	9.2	11.6
5 x 5 x 4 blocks high	2:1	23.5	24.5	**25.9**
	1:1	11.5	13.8	**15**
	1:2	5.5	7.3	**8.3**

Table 2
Medians of VDF of all 27 scenarios.

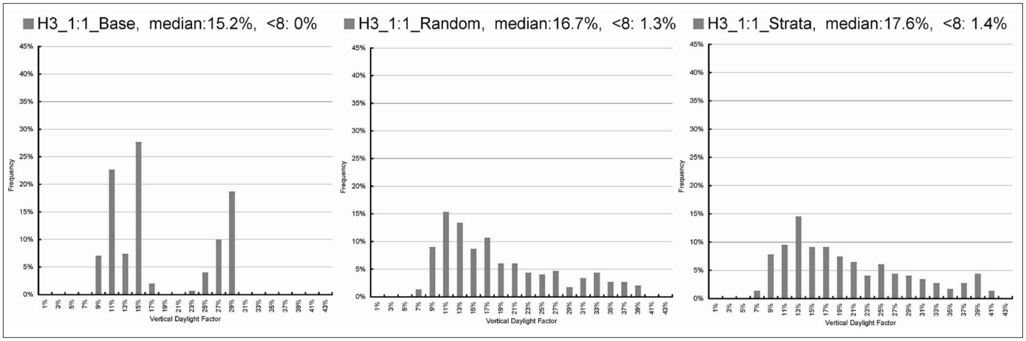
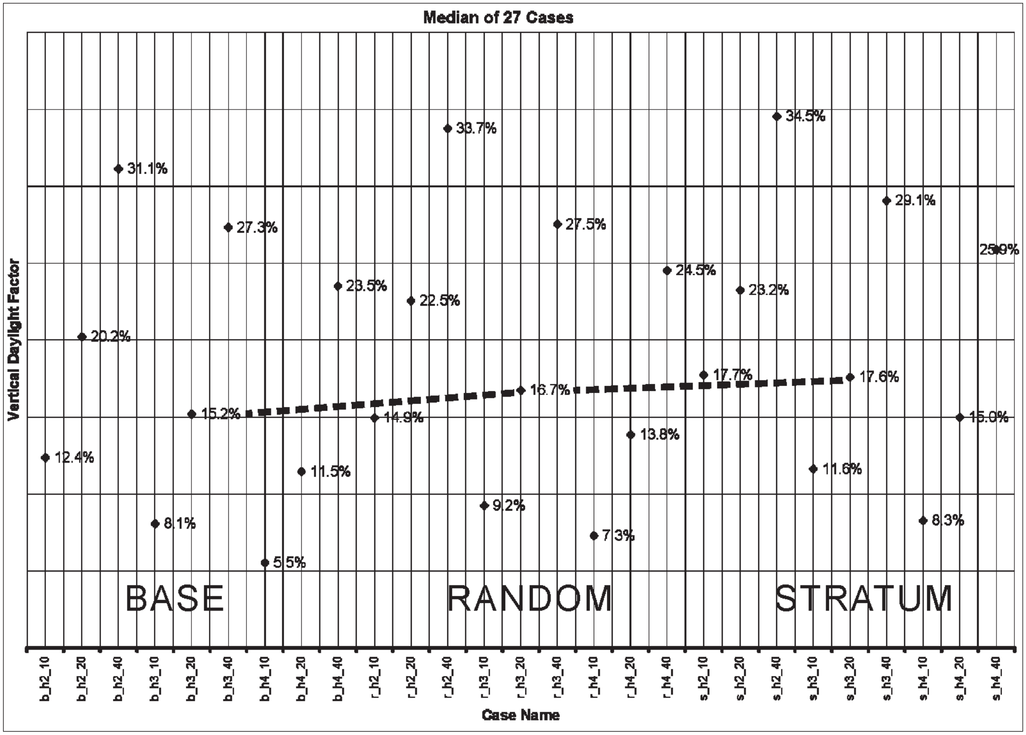


Figure 5
VDF performance (x-axis) was plotted against the cumulative occurrence (y-axis).

Figure 6
Medians of VDF of 27 scenarios. Note the general shift from left to right.



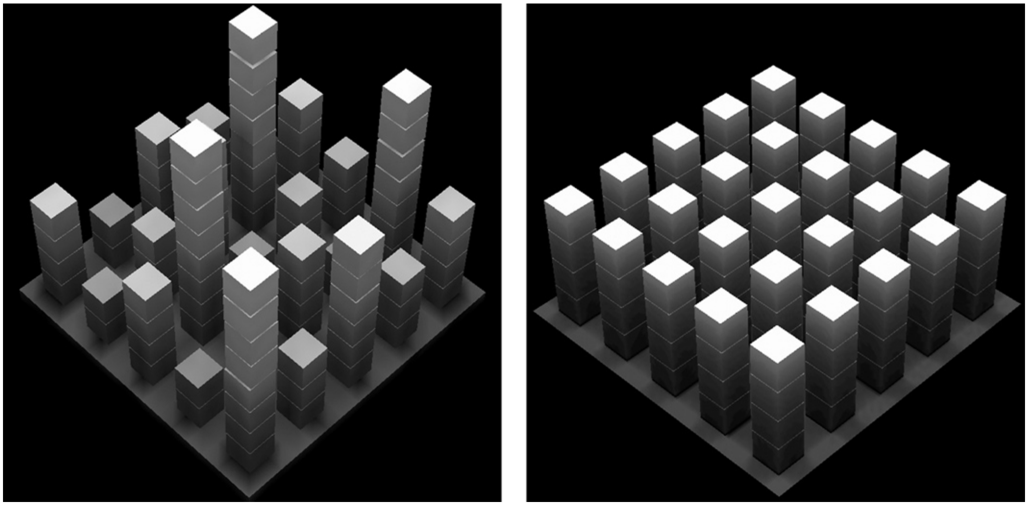


Figure 7
Daylight performance of a city with random building heights (lift) is better than one with the same height (right) given the same density.

rameter as stated in this study, what is the range of building heights one should recommend? Is there is simple mathematical formula to describe the relationship? Can an optimum solution be found and expressed mathematically?

This parametric study is a beginning. It investigated density, building skylines and street width to building width ratios. Other parameters like building shapes, gaps between buildings, permeability of the urban fabric and building surfaces could also affect daylight and air ventilation performances. They require further studies.

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