Computational simulation based daylight design for urban sites – validation, methodology and legality

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Abstract. The creditability of using CAAD depends on the rigour of its methodology, the logic of its deduction and most importantly the feasibility of its results for practical use. This paper examines two lighting simulation software as the basis for providing a wider critic on the research of CAAD in the practice of architecture. The paper argues that the ‘contextual’ and appropriate use of a simple tool or method should be the thesis of CAAD research. Using an example, the paper then logically work out an example of how that could be done, and the basis of its contextual logic. The example illustrated here concludes the validity of the software and its implication for legal use. Furthermore, the paper provides a critic of CAAD for regulatory and legal acceptance. The experience in Hong Kong is illustrated.

Keywords. Daylight design; Lightscape; Radiance; Building regulation; Software validation.

Introduction

One of the key tasks of using computer in design is how well the results mimic and represent reality. Computer graphics and advanced computational simulation has been with researchers in this area of study for many years now, it is now important to bring the tool out of the laboratory into the real practice of architectural design in a formal, logical and reliable manner. This paper reports studies in this direction of pursuit.

There has been arguments on the sensitivity and accuracy of Lightscape® — a daylight simulation and rendering software when compared with Radiance®. Despite all the literatures that support Radiance as the most accurate software for calculation, Radiance however, from the user point of view is quite difficult to manipulate. It is not as user-friendly as Lightscape. Thus for a designer, the tool is accurate but not very usable. The problem poses some pedagogical issues. Should we use a design tool that is not friendly but more accurate, or should we use a tool that is friendly but may not yield useful results? Which of these tools could bring design closer to reality – both in the reality of design and in the reality of representation?

The question is incomplete, for it misses a critical point. The point is that it may be possible to seek circumstances and conditions that a friendly tool could be adapted to a design that would yield useful results as well. This paper is an attempt to provide that scenario. It represents the continuation of efforts and papers published previously in CAADRIA, ECAADE and CAAD Future on this issue.
Issues

Which tool is better, more advanced and represents the latest development of scholarship and technology: a hammer or a bulldozer?

The answer logically, and to some strangely enough, has to be the hammer when the circumstances warrant it, for example, when putting a nail to the back of the door. Thus the question should really be rephrased to include the conditions of application of the tool. Likewise, in computational studies, it is useless to aim for a tool that only address the general and undefined conditions of the problem. A naïve justification of the approach keys on the notion that design is a problem that is fussy and general enough to merit a similarly fuzzy approach. Sadly, many knowledge coding and indexing and information system sin against the common sense by offering solutions designers may need ‘at all time’.

Computational simulation studies are not immune to the abuse. It has long been heralded that the most sophisticated and advanced lighting tool that could account for the final 0.1 lux of light of complicated scene should be regarded the best and the only tool to use. Software that is deficient in terms of its in-built algorithms and mathematical model should automatically be discarded, even if they are easier to use and more design friendly.

The issue should not be approached in an either/or scenario. For a key question that could be asked is that: under what circumstances and allowing what accuracy limits should a tool be used despite its scientific discredit-ability? In short, when is the hammer a suitable and better tool?

The science of tool making therefore is no longer pure science. It has to include the conditions of application. And in that particular condition, the dilemma of science, design practicality and more importantly legality are all key factors testing our methodology, logic of argument and the ultimate results. This is the central thesis and basis of this paper.

The study

In Hong Kong, due to its high-density nature, designing for daylight is a major task. Building regulations exists. (HKSAR 1959) The government of Hong Kong recently approved submissions that make use of computational simulated results. A performance-based approach is now acceptable. Many manual methods exist. (Tregenza 1998; Baker et al 1993). However, like computational methods, some of them are not designed for high-density cities. (Ng 2001b). There is a need to search for solutions.

Using scale model measurement and simulated results, the study aims to provide designer and regulators a design method that is friendly for design, easy to regulate, robust in providing reliable results, and ultimately is objective and enforceable in front of the laws. To achieve that, the study investigates settings that might be used, validate the two software with real data, note the error limits, and proposes a way forward.

Radiance is reputed to have an accurate CIE sky model. (Ng 2000). Lightscape on the other hand has never been tested. A simple experiment was set up to establish: at what set, if at all, Lightscape could yield an accurate sky model. The CIE Standard Overcast sky is defined by: Lq=[Lz ( 1 + 2 sinq )] / 3. Note that Lq increases as one look towards the Zenith (Lz) of the sky from the horizon. Indeed, it is 3 times brighter overhead than on the horizon. Moreover, the brightness of the sky is independent of the orientation (azimuth independent). That is to say, in very cloudy sky, the south looks as bright as the north. Taking this as the starting point, a special model was built in Lightscape to test the Luminance of the sky of different altitude. Special ‘tubes’ were
created facing the four cardinal points at 15 degree interval. A special surface was set at the rear of each tube. The tubes were of black colour. Thus, the amount of light receivable at the surface would be proportional to the brightness (and therefore the Luminance) of the sky in front of the tube. Such a set up is extremely useful to calibrate the sky model in any software.

A number of setting were tested including: quality of rendering, position of the sun (elevation and rotation), sun illumination, times and dates, accuracy setting of the sky calculation, subdivision contrast threshold, sky light accuracy, and sky conditions. For the settings, it was found that sun illumination (must be set to 0) and sky conditions (must be set to Cloudy) were the two most important settings.

Based on results of the parametric study of some 40 different settings, the result as shown in Figure 2 appears to yield the closest match. It was noted that Lightscape is inaccurate at low altitude (37% of error at 15 degree). However, at high altitude, it was fine. It was noted that at an altitude of 60 degree or more, the error is less than 5%.

The experiment and observation highlighted two important points. Firstly, the critics are right, Lightscape is not accurate (as far as the sky model is concern). The sky model Lightscape has resembled more the uniform sky than the CIE sky. However, it was also noted that at high altitude sky, the error is small. The question to ask is: under what circumstances that only high altitude sky is important in daylight computation? The answer is obvious. If a surface is surrounded by high obstruction exceeding 60-degree, and the sky patch the surface can see is at 60 degree or more, then the likely error from the sky model will be small.

Typically circumstances of the above scenario do not exist. But in Hong Kong, it does (see Figure 3). Building regulations in Hong Kong
allow building obstructions up to 71.5 degree to be built. Typically they are built to that height. Hence, the amount of the sky that a surface on the ground can see is small and is limited to high altitude sky only.

Therefore, it may be argued that Lightscape’s inaccurate sky model may not be a problem at all. Indeed, scientifically, any software with a uniform sky model will be fine for conditions in Hong Kong.

The next question to ask is: given the tolerance accepted in the Global Illumination Model (sky model) of the software, is the Local Illumination Model (inter-reflection model) used reasonable to the task? The question could best be investigated with another test. Local illumination model could best be investigated with scenes that involve second or higher order reflections. The ability to accurately account for the bouncing of light among surfaces is the key measure.

24 testing scenarios were constructed to test the correlation between Lightscape and on-site measurement using scale models and the real sky. (Love 1991; Mardaljevic 1997) Refer to Figure 4, 7 mini-photometers were planted into a wing of one of the block. The block was surrounded with a highly obstructed surrounding resemble of housing estates in Hong Kong. Figure 4 shows an example of the 24 scenarios used. All surfaces in the computer model and in the scale model were set at r=0.2.

The 7 sensors along the height of the block allowed a whole range of data to be collected. The top sensor could almost see the half hemisphere of the sky dome. Theoretically, due to the poor sky model used in Lightscape, it should give the worst result. The bottom sensor on the other hand could see light mostly reflected from the surrounding surfaces. Hence the reading should relate closely to the accuracy of the Local Illumination Model used in the software.

Figure 5 shows three examples of the 24 results. Note that the graph on the left indicates that Lightscape and measurement match very closely at all 7 sensor points. The graph on the right indicates that the error is constant across the range, and that Lightscape underestimate results by about 2% to 3%. Further investigation indicates that the differences could be attributed to the layout of the blocks in that for more open space in front of the sensors, the results would...
shift more to the graph on the right, whereas for tighter open space and hence less direct sky onto the sensors, the results would shift more to the graph on the left. In general, the graph in the middle is the norm. This indicates that results of Lightscape are very accurate for the bottom sensors and deviate more towards the top. This indicates that its Local Illumination Model of Lightscape works reasonably well.

Figure 6 shows a summary of results of the 24 scenarios. There are 7 sensor positions. At each sensor position, results of the 24 scenarios are analysed. The upper and lower quartile, and the medium are plotted. The upper sensors (6 and 7) recorded error to around 15%. Lightscape underestimates. However, at the lower sensors (1 and 2), the results match very closely.

Figure 7 shows the percentage error between Lightscape and measured data. It should be noted that at the bottom of the towers, where direct Sky Component (SC) of the surfaces is small, results obtained with Lightscape is very close to that obtained using scale models under the real sky. From the results, it can be noted that Lightscape slightly under-estimate daylight performance. Further fine-tuning of the results could be set using the reflectance of the surfaces. (It should be noted that for legal purpose – which will be outlined later in the conclusion – it is prudent to slightly underestimate so that in the majority of cases, the real results could be equal or better than the simulated results.)

Figure 8 shows an example of Radiance result.

Figure 9 shows the percentage error between Lightscape and Radiance. Having established the accuracy of the illumination models used in Lightscape, it may be prudent to compare it with Radiance (repute to be a more accurate software). 10 scenarios were constructed; again with high-rise blocks of different spacing, see Figure 8. Since one is typically more interested in daylight performance near the ground, only values at the bottom of the buildings were noted and compared.
The four facades of a block in the middle of each of the scenario were measured. The results are presented in Figure 9.

The results here largely agree with previous studies comparing the software. (Ng 2001a and 2001c) Although Radiance has a better sky model (Global Illumination Model), it seems to perform rather poorly with its inter-reflection modeling (Local Illumination Model). That is to say, it has the tendency to overestimate results of daylight performance on surfaces receiving light largely from reflected sources. Radiance is however reasonably accurate at scenes of lesser obstructions. This is also in line with many studies of Radiance around the world.

It could be concluded that for scenes of high obstruction, the lesser software (Lightscape) could be used.

The road ahead

Since 2003, the Government of Hong Kong has allowed architects and engineers to submit design using a performance based approach. For daylight provision of residential buildings, it stipulated that the vertical surfaces of the building containing the window should receive no less than 8% Vertical Daylight Factor (VDF). It is up the architect to demonstrate that the design satisfies with the legal requirement. Since then, many architects turned to computer simulation. Various software have been used, and mostly without a basic understanding of the logic. One might argue that most of the time, the tools were used out of its context and boundary of limits.

The Government is aware of the dilemma. On the one hand, she is trying to encourage a flexible performance based approach to design, but on the other hand, she has to find a way to guide the process and to prevent misuse. Lately, 10 standard models with known results have been set up. The ten models were created to test software’s performance under different conditions. They are a bit like benchmarking software in the IT world. Accuracy is under test. The idea is that if the proposed software to a certain setting could generate results within a 10% error range of the standard results, the software at that setting is deemed to pass the validation test. The results thus generated could be considered valid and legal. Studies of this paper therefore contribute to knowledge in this way.

Computer aided design has gone a long way. Developing and using the right tool has always been the key issue. Following this study, the right tool has more to offer than simply tackling the job itself. In Hong Kong the process has entered the ‘legal’ and ‘regulatory’ requirement of demand and rigour. Hence it is time to get serious so as to earn its creditability. The accuracy through validation, its accepted bound of errors, its logic of methodology, precautions of its operational inexactness, and its practicality and usefulness as a working tool for a very precise context must be established. (Ng 2003). This paper offers a step in that direction.

The same rigour and logic is also true with any other branches of CAAD. ‘Garbage in, garbage out’, a common term in CAAD, is beginning to be an understatement. Nowadays, one can be sued for misrepresentation – even with computer generated results. Hence, there is no point creating empty shells of frameworks or ‘make believe’ systems that could not be used, verified or evaluated. Unfortunately, some recent so call ‘case base’ learning or ‘smart’ knowledge indexing systems, and CAD based knowledge packages belong to this type of offering. It is not scholarly to pretend results when only a hypothesis is offered. How good a system or methodology is depends on how it performs, not how it is structured or theorised.

Although the topic of this paper is about validation of computer simulation software for a pur-
pose, the message has to go further. The seven sins of CAAD, as prophesized by Tom Maver in the keynote speech of CAAD Future 1995 Conference is still with us. In the world of legality, which the works of this paper is part of; the sins will not be tolerated. Bluntly, they could put you to jail.

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