

CALCULATION METHOD OF SKY VIEW FACTOR BASED ON RHINO-GRASSHOPPER PLATFORM

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ABSTRACT

In this study we presented a new numerical method to calculate sky view factor (SVF) based on Rhino-Grasshopper platform, aiming to provide possibilities opportunity to evaluate detail distribution of SVF in scheme stage of buildings and urban. The procedure of calculation is briefly showed as follows: 1) the 3D database of scheme or site is imported by Grasshopper, and a certain resolution of measuring points are arranged. 2) SVF is computed for all the measuring points one by one, and the continuous SVF field was finally achieved. 3) the results result are sent to Excel and displayed on 3D visualization. By calculations and comparisons of different models, we determined four key parameters while balancing calculation accuracy and efficiency. It is worth noting that the bisection method is highly efficient and of less error in contrast with equisection method, especially when the height-width ratio of canyons is relatively high. Besides, the effect of the buildings around could be considered negligible while they are beyond the scope of 100m extended region.

Key words: detail distribution of SVF, Rhino-Grasshopper, a numerical method

INTRODUCTION

Sky view factor (SVF) is the ratio of radiation received by a planar surface from the sky to that received from the entire hemispheric radiating environment (Johnson et al. 1984). SVF=1 means that the radiation which is released by a surface is totally received by the sky, while SVF=0 means that the radiation is completely blocked by obstructions. SVF is an important parameters to describe long-wave radiation exchange within urban canopies, and SVF field is significantly affected by the distribution and sculpt of surrounding buildings (Oke 1988, Sakakibara 1996). Therefore the detailed distribution of SVF plays an important role in relating the distribution or sculpt of buildings to urban thermal environment.

Several methods have been proposed to calculate SVF, and the below is brief review:

- Analytical methods. Use equations and geometrical characteristics as input to calculate SVF, and suitable for simple models. For example,

Oke(1981) proposed a method to calculate SVF of the center point of a symmetric canyon of infinite length (OKE 1981, Johnson et al. 1984), and Johnson and Watson (1984) extended the method and established expressions for nonsymmetrical canyons of finite length (OKE 1981, Johnson et al. 1984).

- Fisheye photographic methods. Project the hemispherical environment onto a circular plane, and the image is processing manually or by computer to get SVF (Steyn 1980, Watson et al. 1988). These methods are introduced for complex real environments, and not suitable for evaluation of SVF in design phase.

- Numerical models methods. Developed for the SVF estimation in the built or schematic design phase of urban environment. The methods can be divided into three categories: stand-alone programs(Bruse et al. 1998, Teller et al. 2001), CAD plug-ins (SHU 2009, CHEN 2010, CHENG 2012), and non-CAD plug-ins(Ratti et al. 2004, Gal et al. 2007, Gal et al. 2009). The CAD plug-ins is particularly well suited for designers for that they can evaluate rapidly at design stage by use their existing CAD models. However, SVF of single point or average of an area can only be calculated by using the existed methods, and therefore, it is still difficult to accurately evaluate the effect of 3D geometrical configuration on long-wave radiative heat loss(CHEN 2010)(CHEN 2010). Meanwhile, Yafeng Gao (GAO et al. 2012)indicated that when increasing height-width ratio of canyon and using equisection method to estimate altitude angle, it usually makes the precision of SVF calculation descend.

The main purpose of the present study is proposed a numerical method to calculate continuous distribution of SVF of urban environments based on Rhino-grasshopper platform. The specific objectives are: (1) to present two methods, bisection& equisection, for estimating altitude angle, and compare in their performance and applicability; (2) to determine appropriate parameter settings of the calculation.

NUMERICAL METHOD OF SVF FIELD ESTIMATION

The SVF calculation plug-ins was written by VB.net and based on Grasshopper (GH). GH is a graphical

algorithm editor tightly integrated with Rhino's 3D modeling tools.(www.grasshopper3d.com,2012). Fig. 1 illustrates the schematic description of the plug-ins. With the help of GH, the plug-ins can quickly get the vector data of buildings and set up the computing grid for SVF calculation. When the calculation is completed, the results of continuous SVF field will be outputted to Excel, and displayed on 3D visualization.

Method of single-point SVF estimation

The method proposed by Gal (2009) was adopted to calculate SVF of single-point. There were four key steps in this method (Fig. 2):

1) create a hemisphere of unit radius in a 3D model, and place the center of the hemisphere at the measuring point. 2) divide the hemisphere equally into n slices by rotation angle($\alpha=360/n$). 3) estimate altitude angle for each slice(β_i), which was the largest altitude angle that was obstructed for that slice. The wall view factor for a slice with a width of α was: $WVFi=(\alpha/360)*\cos^2\beta_i=(1/n)*\cos^2\beta_i$. 4) calculate the SVF value of the measuring point as: $SVF=1-WVF=1-\sum_{i=1}^n WVFi$. The accuracy of the above method depended on two aspects: the way to measure the altitude angle(β_i) and the slices number (n).

Two methods, that is the equisection and bisection method, were considered to be used to measure the altitude angle. The main steps of the two methods were shown below.

The major steps of the equisection method are(Fig. 3a): (1) divide the slice(s) equally into M sectors by altitude angle $\beta_e=90/M$ and draw virtual detection lines from the measuring point to each sectors. (2) calculate the amount of lines that intersected with solid obstacles(buildings), which was termed as m, and the altitude angle was determined as $\beta_i=\beta_e \times m = m \times 90/M$. It can be known that a higher value of M will result in a more accurate estimation of the β_i and a longer computation time. In this article, the value of M was 90.

The steps for bisection method(Fig. 3b) can be described as follows: (1) set a convergence threshold C(in this article, $C=0.001$). (2) draw virtual detection lines by the altitude angle β_b from the measuring point. And the angle β_b is calculated as:

$$\beta_b = \beta_{b-1} + (-1)^T \times \Delta\beta_b$$

where $b=0,1,2,\dots$, $\beta_0=0$, $\beta_1=45$, $\Delta\beta_b=90/2^b$. If the lines intersect with any buildings, then $T=0$; if not, then $T=1$. (3) compute the differences of wall view factor ΔWVF , and if $\Delta WVF \geq C$, then repeat the step 2 and 3; if not, then calculation is finished and the altitude angle of the slice(s) $\beta_i = \beta_b$. The value ΔWVF could be derived by the following formula:

$$\Delta WVF = |n \times (WVF_b - WVF_{b-1})| = |\cos^2\beta_b - \cos^2\beta_{b-1}|$$

Method of continuous SVF field estimation

The estimation method of continuous SVF field includes the following steps. (1) set up the total computing area (Fig. 4), which contains two major parts: central region and extended region. (2) arrange the measuring points evenly in a proper resolution within the central region. The points overlapped by the buildings were deleted. (3) determine the SVF of each points by the method of single-point. The buildings located in extended region will be taken into consider when performing the estimation of SVF field.

There were mainly two factors influencing the accuracy of the above method: the resolution of measuring points and the rang of extended region. The optimal settings of the influencing factors should be determined while considering both the precision of the calculation and the necessary computing time.

DETERMINATION OF KEY PARAMETERS

Inappropriate settings of key parameters would lead to low accuracy and more computation time. The key parameters were determined in the present study with the considerations of both accuracy and calculation time. The value of relative error (δ) was used to represent the accuracy of calculation, which was derived by the following formula:

$$\delta = (SVF_{est} - SVF_{ref}) / SVF_{ref} \times 100\%$$

where SVF_{est} is the result calculated by the numerical method and SVF_{ref} is the reference value to be compared(e.g. analytical solution for Model I&II, and calculation results by the method with high level settings for Model III&IV).

Determination of altitude angle

(1) Model I

Model I (Fig. 5a) was a hollow cylinder with a certain radius $R=10m$. The height(H) of cylinder was changed from 1m to 100m in step of 5m, and therefore the H/R ratio of the cylinder changed from 0.1 to 10. The measuring point(MP) was located at the central of cylinder. According to analytical solutions, the reference value of model I could be derived with the following formula:

$$SVF_{ref-MI} = R^2 / (H^2 + R^2)$$

The relative errors (RE) can be expressed for various methods as:

$$\delta_{equisection} = (SVF_{equisection} - SVF_{ref-MI}) / SVF_{ref-MI} \times 100\%$$

$$\delta_{bisection} = (SVF_{bisection} - SVF_{ref-MI}) / SVF_{ref-MI} \times 100\%$$

Where $SVF_{equisection}$ is the SVF value based on the altitude angle estimation method of equisection, $SVF_{bisection}$ is the value based on the method of bisection.

(2)Results

The RE of two methods were shown in Figure 6. It can be seen that the maximum RE of equisection method(EM) was 35%, which is about 7 times of that of bisection method(BM). The mean RE of EM was

10%, nearly 5 times of that of BM. When the H/R ratio increases, it is worth noting that the RE of EM increases rapidly, and when H/R ratio is above 3, the RE of EM starts to rise above 5%, and, therefore the EM is not suitable for SVF calculation under the condition of such high H/R ratio.

Figure 6 also shows the time-consuming under different conditions. The mean time-consuming of EM was 2289ms, 7 times as that of BM. In addition, it can be seen that the computational efficiency of BM was not sensitive to H/R ratio.

As the above results show, the bisection method was highly efficient and of less relative error in contrast with equisection method while estimating SVF. Hence, the bisection method was used to determine altitude angle in the following sections.

Determination of slices number

(1) Model II

Model II was a nonsymmetrical canyon with finite length (Fig. 5b). There were two buildings in different heights in the model. The length (L) of the canyons was varied from 1m to 100m in step of 5m, and the other geometrical characters, such as width(W) of the canyons (20m) and heights of buildings(50m and 20m) were fixed as constant. The MP was placed at the midpoint of the canyon. Johnson and Watson (1984) proposed a analytic method based on azimuths(γ) and altitude(β) angles of surrounding buildings, which involved calculating the wall view factors(WVF):

$$WVF_{M2} = \frac{1}{2\pi} \{ (\gamma_2 - \gamma_1) + \cos \beta [\tan^{-1}(\cos \beta \tan \gamma_1) - \tan^{-1}(\cos \beta \tan \gamma_2)] \}$$

Where γ_1 and γ_2 are the azimuth angles of the finite wall from MP to the two ends of the wall, and β is the angle of elevation of the top of a wall from the line parallel to the wall, passing through the MP. The wall view factor of MP surrounded by several buildings would be the sum of the WVF for each building. According to analytical solutions, the reference value of model II could be derived with the following formula:

$$SVF_{ref-M2} = 1 - (WVF_{1-M2} + WVF_{2-M2})$$

To compare accuracy of the different magnitude, the RE between the results of analytical method and the numerical methods was:

$$\delta_n = (\overline{SVF}_n - \overline{SVF}_{ref-M2}) / \overline{SVF}_{ref-M2} \times 100\%$$

Where n was the parameter setting of slices number, in this case, n=90, 180, 360, 720, 1440, and \overline{SVF}_n was the result in the settings.

(2)Results

As the Fig. 7 shows, there was negative correlation between the slices number and the mean value of RE, and positive correlation between the slices number and time-consuming of computation. The mean values of RE were always smaller than 1.5% for

Model II. Form the aspects of accuracy and efficiency, the slices number could be determined as 360.

Determination of resolution of measuring point

(1) Model III

Model III (Fig. 5c) included two urban sites in different scales that were generated by randomly arranging a certain amount of buildings. According to the national architectural design specifications of China(93 2002), the dimension of dwelling group in the Hot-Summer and Warm-Winter area is 12000~48000m², so the central region of Site A was determined as 200x200m, including 30 random arranged buildings (cuboid), and Site B was 400x400m, including 120 buildings.

To compare the accuracy of different resolutions, the results calculated in resolution of 2.5m was considered as reference, and the RE of other four different resolutions was:

$$\delta_{Resolution-x} = \frac{(\overline{SVF}_{Resolution-x} - \overline{SVF}_{Resolution-2.5})}{\overline{SVF}_{Resolution-2.5}} \times 100\%$$

Where x was the parameter setting of the resolution, in this case, x=2.5, 5, 10, 20, 40(only Site B) and $\overline{SVF}_{Resolution-x}$ was mean value of the calculation results in the settings.

(2)Results

As the Fig. 8 shows, the resolution of the MP correlated with the mean value of RE negatively and with time-consuming of computation positively. The intersection point of the regression lines with the Y axis was the estimation RE between the setting resolution and the 0m resolution. The estimation RE of 5m resolution were 2.4% for Site A and 3.3% for Site B, both of which are less than 5%. The estimation RE of 10m resolution was 6.7% for Site B, which is greater than 5%. Form the aspects of accuracy and efficiency, the resolution of measuring points was determined as 5m.

Determination of extended region

(1) Model IV

The total region of Model IV was 900x900m (Fig. 5d), and the buildings outside of extended region would not be taken into account during the SVF calculation. The calculation region contained central region and extended region. The MPs were evenly distributed in the central region (200x200m). The extended region was changed in distance of 0m to 250m from the central region and Table 1 summarizes the information of the extended regions.

To compare effects of the different range, the results calculated in range of 250m was considered as reference, and the RE of other six range was:

$$\delta_{R-y} = \frac{(\overline{SVF}_{R-y} - \overline{SVF}_{R-250})}{\overline{SVF}_{R-250}} \times 100\%$$

Where y was the parameter setting of the range, in this case, $y=0, 25, 50, 100, 150, 200, 250$ and SVF_{R-y} was mean value of the calculation result in the settings.

(2) Results of the Determination

By comparing the calculations of the different ranges (Fig. 9a), it can be found that continuous SVF field nearby the edge was greatly influence by the buildings in the extended region. The result (Fig. 9b) denoted that whether or not to consider the surrounding buildings could lead to a maximum error of 56% in mean value of SVF. When considering the buildings in the extended range of 50~100m, the error could decrease to 3.6% or less, and the error could decrease to 0.8% while the considered range was over 100m. Based on the above results, extended region range was determined as 50m or 100m.

CONCLUSION

The numerical method based on CAD plug-ins on Rhino-Grasshopper platform was proposed and the key parameters were determined while considering both accuracy and time-consuming. The method provides an efficient and accuracy way to estimate both the single-point SVF and continuous SVF field. The bisection method is highly efficient and of less relative error in contrast with equisection method while estimating altitude angle. The impact can be ignored for the buildings 100m far away from the central region. Table 2 summarizes the proper settings for SVF calculation.

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Figures and Tables

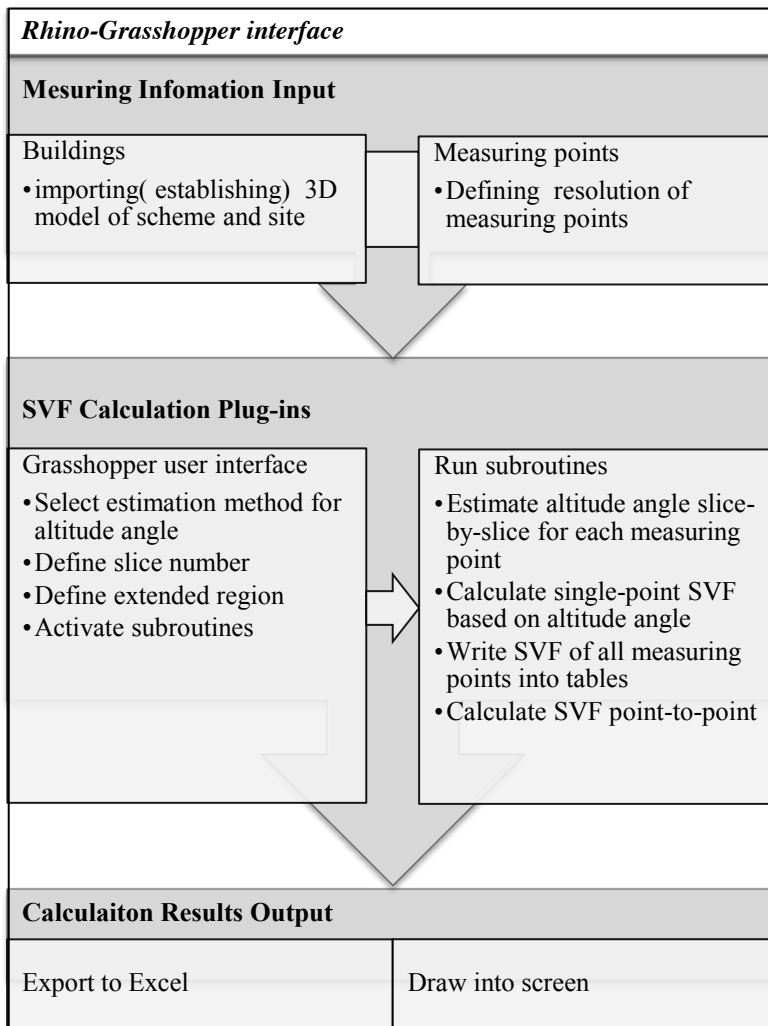


Figure 1. Schematic description of the algorithm for the detail distribution of SVF calculation based on the Rhino-Grasshopper platform.

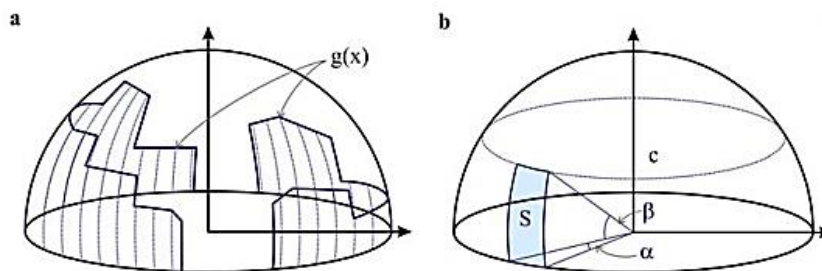


Figure 2. Illustration of method of Single-point SVF estimation (Gal et al. 2009). (a) Polygon $g(x)$ as a border of the visible sky and dividing the hemisphere under $g(x)$ equally into slices by angle α (heights are equal to the $g(x)$ values in the middle points of the interval), (b) a slice of a 'width' of a (S) of a basin with an altitude angle β

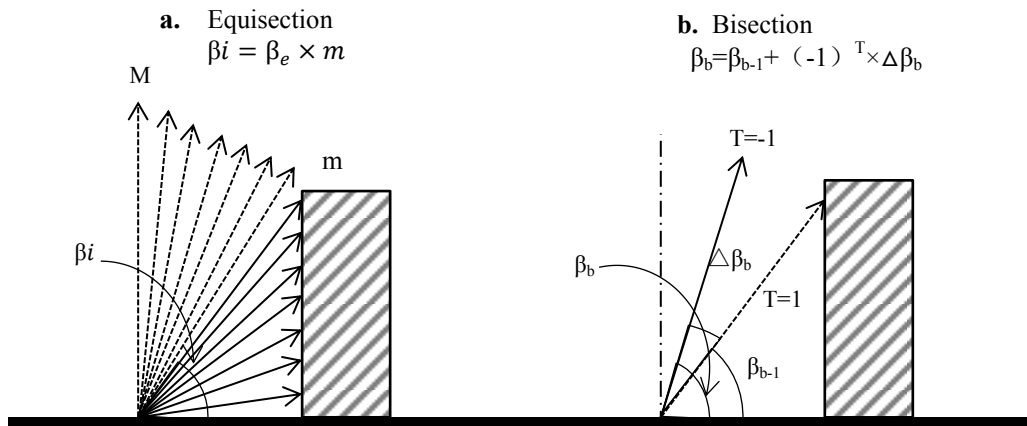


Figure 3. Illustration of (a) equisection method, (b) bisection method

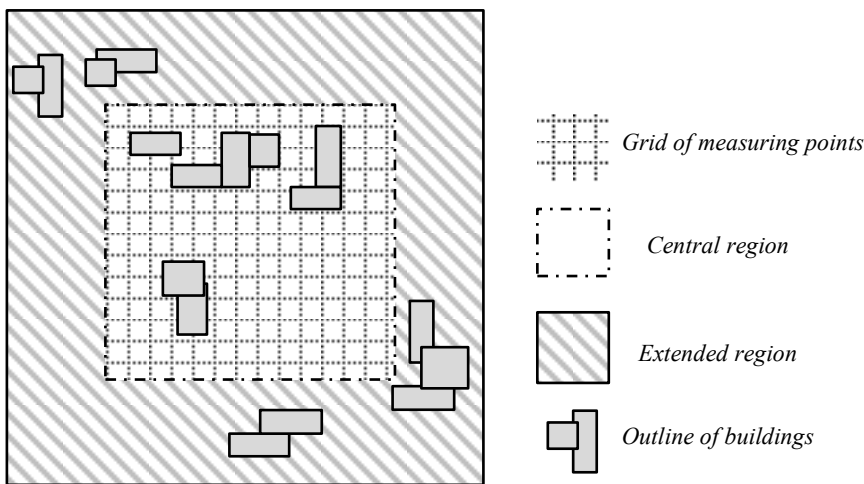


Figure 4. A sample with the total computing area

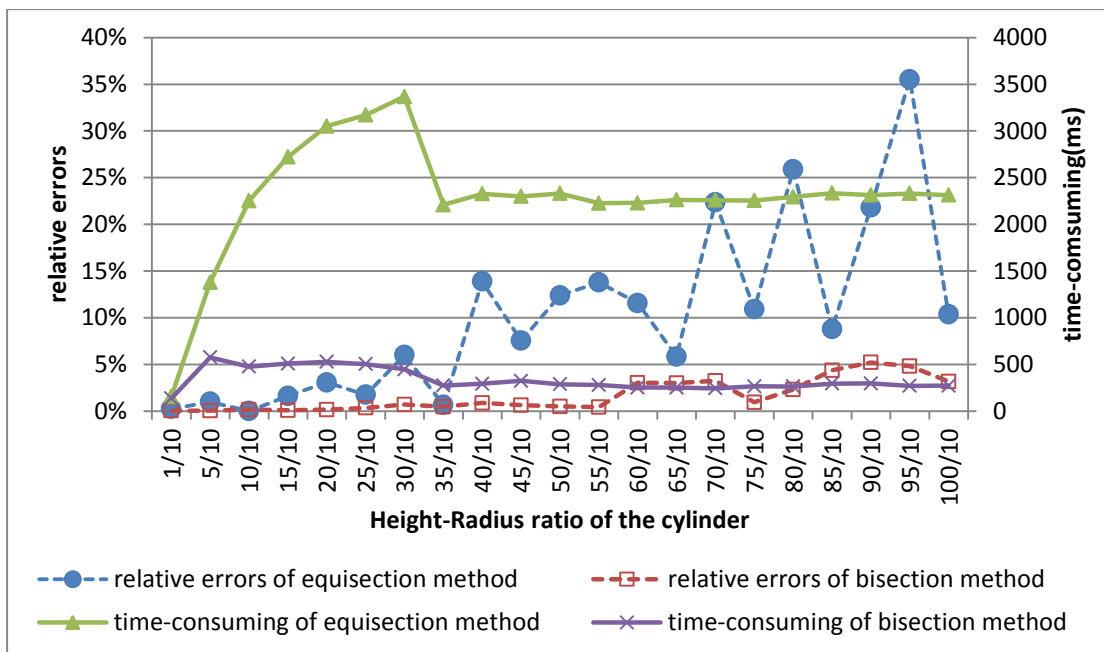
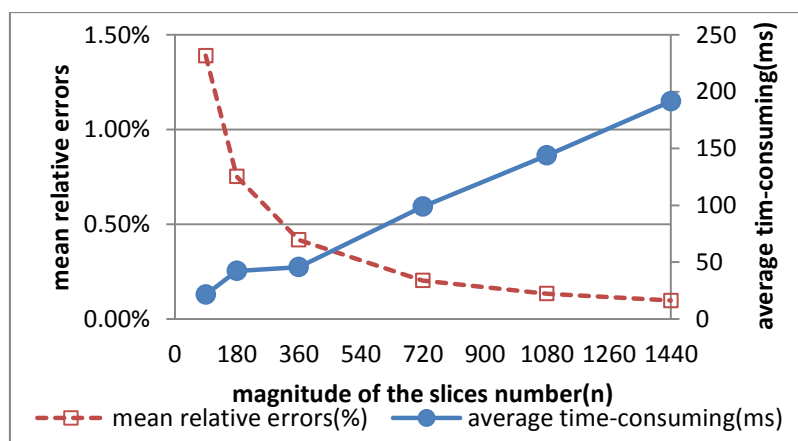
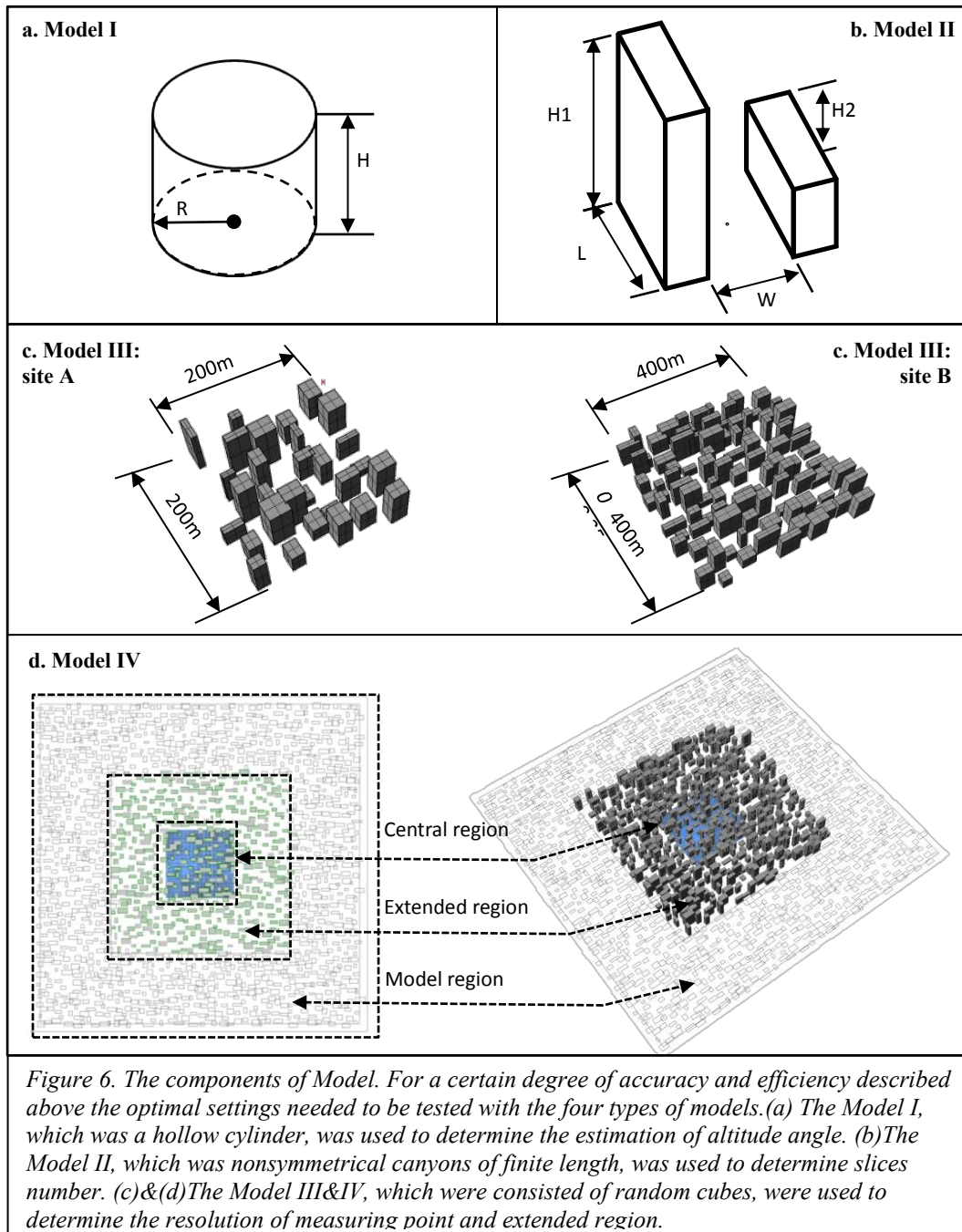


Figure 5. The comparison of relative errors and time-consuming at different altitude estimation method



Information of Site A

Number of buildings: 30
 Central region: 200x200m
 Resolution: 20x20@10m
 Time-consuming: 0.13min
 Detail distribution of SVF:

Information of Site B

Number of buildings: 120
 Central region: 400x400m
 Resolution: 80x80@2.5m
 Time-consuming: 46.6min
 Detail distribution of SVF:

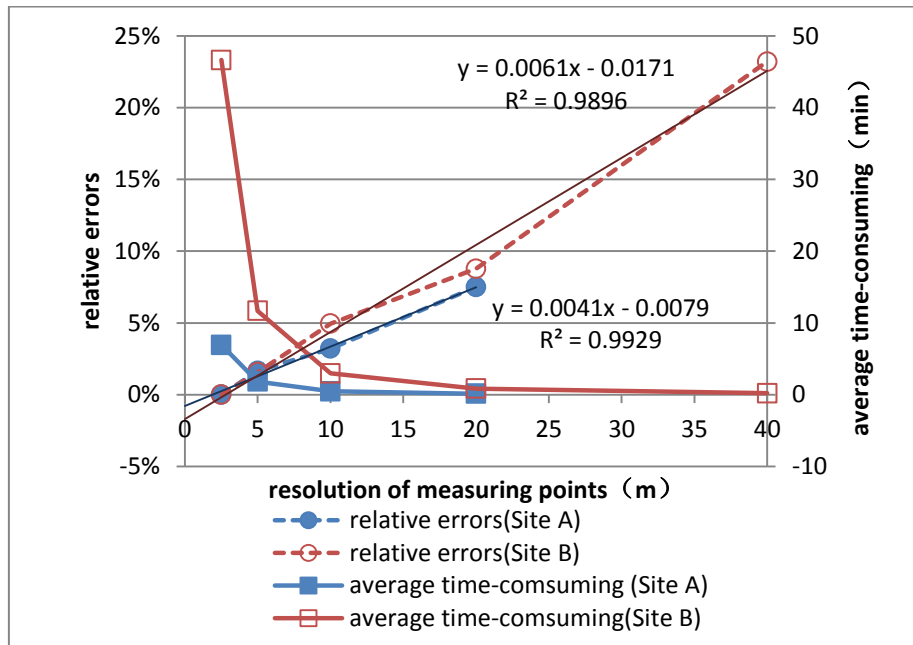
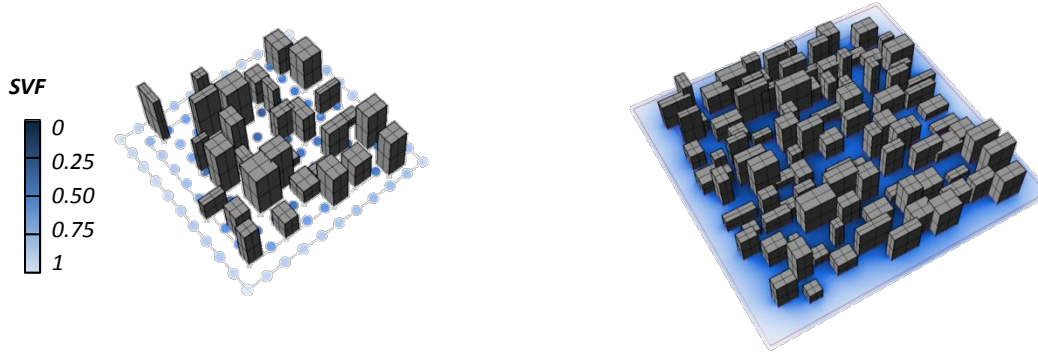


Figure 8. Comparison of relative errors and average time-consuming at different resolution of measuring points

Table 1. Statistic of sites information for various extended regions

EXTENDED REGION (M)	CALCULATIO N REGION AREA(m²)	NUMBER OF BUILDINGS	BUILDING DENSITY	BUILDING HEIGHT(M)		
				MEAN	MIN	MAX
0	40000	26	29.0%	38.9	10.6	84.8
25	62500	44	28.8%	45.4	10.6	89.8
50	90000	66	31.6%	45.1	10.6	89.8
100	160000	116	33.8%	45.9	10.6	89.8
150	250000	176	32.5%	45.7	10.6	89.8
200	360000	256	32.6%	47.6	10.1	89.8
250	490000	342	31.8%	48.6	10.1	89.8

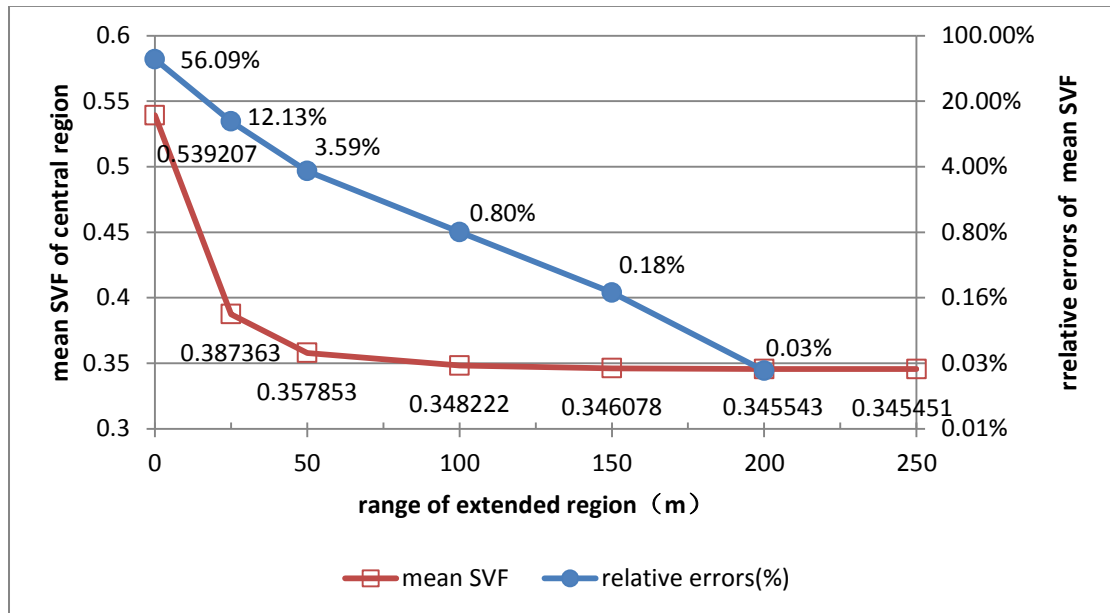
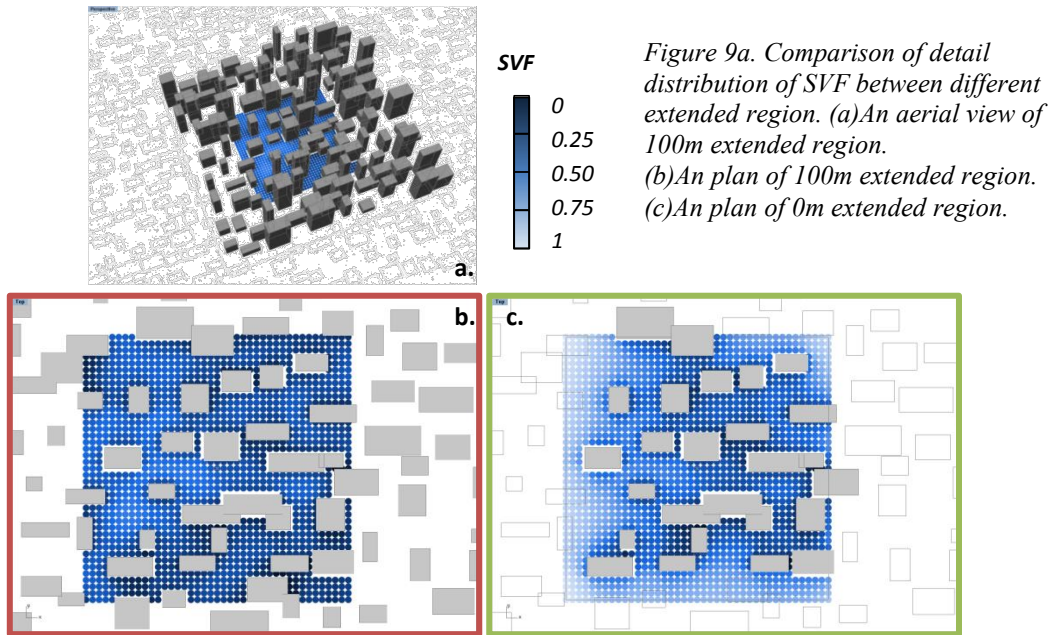


Figure 9b. Comparison of mean SVF and its change rate between different extended region.

Table 2. Recommendation parameter settings of plug-ins

PARAMETER	RECOMMENDATION
SLICES NUMBER	360
RESOLUTION OF MEASURING POINT	5m
RANG OF EXTENDED REGION	50m or 100m