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# Generation of 3D View Map Using by Raster Base Data Processing

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## ABSTRACT

The authors have developed a new method called "Polygon Shift Method" (named so by the authors) that enables to the generation of a 3D view map of a city with tall buildings with a simplified procedure to shift a polygon and check the overlap between the original and shifted polygon. Boolean operations are applied with a newly defined "Fore or Aft" side and a "Depth Distance" that functionize the visibility criteria or hidden point processing in the 3D view.

Because the polygon shift method can be operated with raster based structure the computer processing was effective in visualizing a 3D view map of buildings with shadow.

## 1. INTRODUCTION

Perspective of a building or landscape used to be drawn manually by architects. Since computer aided design (CAD) was introduced in the 1970's, automated drawing became popular (Murai, 1997,Wilson 1998, etc.). In the recent decade, virtual reality software is available to produce perspectives or bird's eye view of three dimensional structures.
However, data format and structure are not yet very simple, because all details not only of the building plan but also nodes, edges and surfaces (vertical walls and roofs) should be input with specified topology. Various data structures of 3D GIS has been proposed by Molenaar (1990), Shibasaki (1992), Chen (1994), Temfli (1997), William (1997) etc. All these data structures are based on "vector base" topology.

The polygon shift method proposed in this paper needs a simple data structure of a polygon (building plan given by vector data as the input data) to generate a raster belonging to the polygon. Data about roof and vertical walls are not necessary because the method is only targeted to column shaped buildings with flat and horizontal roofs though any complicated buildings can be formed with a combination of multiple columns.
Using vector data, the geometry to achieve hidden point/line/surface processing for multiple buildings needs a very complicated algorithm when the building shape includes concave parts. For example, the intersection of lines and surfaces and the identification of overlapped areas of two polygons will be a complicated calculation for concave polygons. A comparison between the proposed method and existing algorithms of Z-Buffer, Scan-Line and Back-Face Removal is described in the section 5.

In this study, a raster mode approach with Boolean operations works effectively to identify overlapping areas using the depth distance, which is a criterion to judge which part of a building hides other buildings.

## 2. PROPOSED 3D COORDINATE SYSTEM.

In the conventional method, most of the 3D view maps used to be based on xyz with a horizontal x-axis, an oblique y-axis and a vertical axis as shown in Fig. 1(a).

In this study, we use a different 3D coordinate system called Military Projection with an orthogonal xy system and an oblique z-axis as shown in Fig. 1(b). The benefit of this system is that we don't need to change the original shape of its building plan, while the disadvantage is that the view map looks a little bit strange with oblique buildings.

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## 3. CONCEPT OF POLYGON SHIFT

Polygon shift can be defined as shift of polygons to a certain direction termed as "shift direction" with a small distance termed "shift amount" as shown in Fig. 2(a). Then, the original polygon *A* and the shifted polygon *A'* will create three parts by Boolean operations:

(1) Overlapping area: *A* and *A'*
(2) A part of *A* not included in *A'* : *A -(A* AND *A')*
(3) A part of *A'* not included in *A* : *A'-(A* AND *A')*

In this study, the area defined by (2) is called "Fore" while the area defined by (3) "Aft". Visible parts of vertical walls will be identified by "Fore", while invisible parts will be detected by "Aft".

3D view of a building with the roof and visible vertical walls can be generated by a sequence of polygon shifts with the shift repetition according to the height of the building, as shown in Fig. 2(b). In case of column type buildings limited in this study, the roof represents the finally shifted polygon, while the visible walls represents a series of "Fore" parts. The invisible walls are automatically hidden in "Aft" parts in the shift process.

## 4. DETERMINATION OF HIDING AND HIDDEN PARTS

There would be no problem for determination of hiding and hidden parts, if 3D view images of buildings were displayed on a monitor sequentially in the order from far to close because far buildings would be automatically hidden. This is true only if these buildings have a convex shape as the simple case shown in Fig. 3(a). However, if there are concave shape buildings as shown in Fig. 3(b), it is complicated to judge which building is farther or closer than the other. Therefore, there should be a theoretical criterion to judge the visibility.

In this study, a distance from a visible point on a roof or wall to the base termed "Depth Distance" (see Fig. 4(a)) is used for the determination of hiding and hidden parts. If there are overlapping areas among "Fore" sides, see example shown in Fig. 4(b) a point with a longer "Depth Distance" hides another point with a smaller "Depth Distance". In the shown example, Point A on the roof hides Point B on the wall, which is originally assigned "Fore" visible side according to the definition given in section 3.

In case of two or more buildings as shown in Fig. 5, the depth distance of a point on overlapping polygons between roof and wall, between walls (see Fig. 5(a)) and between roofs (see Fig. 5(b)) allows the determination of hiding and hidden parts. Points $R_{11}$ of building No.1 and $W_{11}$ of building No.2 in Fig. 5(a) and $R_a$ of building No.1 in Fig. 5(b) hide points $W_{21}$ and $W_{22}$ in Fig. 5(a) and $R_b$ in Fig. 5(b) respectively of building No.2.

## 5. COMPARISON BETWEEN THE POLYGON SHIFT METHOD AND EXISTING ALGORITHMS.

### 5.1 Algorithm of the polygon shift method

The polygon shift method is composed of the following steps:

Step 1 : input building plan of buildings in vector mode and the height.

Step 2 : set up a raster of the study area with the resolution as specified by users and convert the input building plans into raster based polygons.

Step 3 : input shift direction as a function of the looking angle and the depression angle, a unit of shift amount as a function of the building height.

Step 4 : clear the buffer of the depth distance of each polygon as an initial value.

Step 5 : shift each polygon with a pitch of the unit shift amount to the given shift direction and add 1 to each shifted polygon as the depth distance.

Step 6 : compare the value of the former buffer with the one of the shifted buffer at each pixel of the polygons and select the longer depth distance.

Step 7 : repeat step 5 and step 6 until all polygons are shifted with respect to the shift amount given as a function of the height.

Step 8 : output the depth distance of all pixels.

Step 9 : assign grayscale or color in consideration of the shading and the shadow effect.

In case of a convex shaped building as shown in Figure 6(a), the polygon shift method results in a visible roof as the shifted polygon and visible walls as the repeated "Fore" parts as defined in section 3. All "Fore" parts are visible in case of a convex shaped building, while some of "Fore" parts are invisible in case of a concave shaped building as shown in Fig

6(b). However, in the polygon shift method, we don't need to classify whether a given building is convex or concave. The steps 5 and 6 implement automatically the determination of hiding and hidden parts regardless of a convex or concave building.

In case of the determination of hiding and hidden parts between multiple buildings, the same algorithm described in the steps 5 and 6 in the repeated process with respect to the height of multiple buildings solves automatically the visibility problem.

The biggest advantage of the polygon shift method is that we don't need to identify one surface and another within a building as well as between different buildings to determine the hiding and hidden parts as usual in the existing algorithms.

The process of the polygon shift in combination of the polygon shift operations and the comparison of the depth distances of each pixel result in a 3D view map with only visible roofs and walls.

### 5.2 Comparison with the existing algorithms

Three algorithms of Z-buffer, Scan-Line and Back-Face Removal Algorithm were selected for a comparative study on the determination of hiding and hidden parts (Harrington, 1987, Z-Buffer website, 1998).

As an indicator of the determination of hiding and hidden parts, Z-buffer Algorithm uses the Z-axis value of each pixel. The idea of the Z-Buffer is similar to the depth distance in the polygon shift in a term of the indicator. The difference is that the procedure of the Z-Buffer Algorithm, both Z-Buffer and Z-Storing has to be implemented for all possible combination of a pair of two different surfaces (roofs and walls) based on pixel based analysis. In this algorithm, it is required to identify where a pixel to be compared is located on which surfaces in a 3D projection plane. This makes the Z-Buffer Algorithm more complicate than the polygon shift method.

Scan-Line Algorithm is basically similar to Z-Buffer Algorithm except that it uses a scan-line instead of a pixel in order to avoid a full-screen buffer memory. Therefore the same disadvantage remains in this algorithm.

Back-Face Removal Algorithm is based on the process to identify surfaces which are front or back and to remove the back faces by finding the normal vector to the plane of polygon. This algorithm seems very simple, but one can not identify which surface hides other surfaces. Therefore it is difficult to expand this algorithm to shadow analysis.

One of the benefits of the polygon shift is that it does not need to give the wall surfaces as the input data. Wall surfaces will be automatically generated in the process of the polygon shift together with visible check by using the concept of "Fore" and "Aft" as well as "Depth Distance". Roof surfaces are always same as the input polygon in shape, but shifted in location, because in this study only column type buildings are considered.

In the existing methods, even those invisible faces that are automatically avoided in the polygon shift method by using the concept of "Aft" should be searched and checked the visibility using complicated geometry.

The disadvantage of the Polygon Shift Method is to need a full-screen "Depth Distance" buffer as same as in the Z-Buffer Algorithm. The required memory depends on the resolution or pixel spacing to represent the input polygons and the shift direction and the total shift amount given by the height of building. Another disadvantage is that the shape of buildings will not be very precise if the resolution of pixel density is low. However there would not be big problems in memory of recent computers including personal computers.

## 6. SHADOW ANALYSIS WITH DEPTH DISTANCE

Shadow is created by inputting a shift direction as an illumination direction, a shift amount and the shift repetition (shadow length) similarly to the case of the 3D view map. In this paper, the polygon shift for 3D view map generation is termed "View Shift", while for the shadow analysis is termed "Shadow Shift".

The polygon shift approach for both cases is exactly the same for checking the visibility of overlapping areas using the depth distance, though "hiding and hidden" analysis in the 3D view map is replaced by "shadowing and shadowed" analysis in the second case.

This visibility check will be implemented only to "Fore" sides in both view and shadow shift. There are four combinations with respect to "Fore" and "Aft", and "View" and "Shadow" shift as shown in Table 1. As the output image for the 3D view of buildings with shadow will be made in "View Shift" space, only "Fore" sides in "View Shift" are taken into account.

Table 1 Visibility Check and Image Output

| Case | View Shift | Shadow Shift | Image Output |
|---|---|---|---|
| 1 | Fore | Fore | Paint dark only in shadowed areas |
| 2 | Fore | Aft | Paint dark in all areas |
| 3 | Aft | Fore | Neglect |
| 4 | Aft | Aft | Neglect |

The concept of shadow analysis using the depth distance only in "Fore" sides of view and shadow shift spaces is shown in Fig. 7. The hatched areas show the case No.2 with "Fore" view shift and "Aft" shadow shift.

The computation time required for the integration of the "View Shift" and "Shadow Shift" depends on the height of building, the unit of shift amount and the resolution of pixel spacing. As the shift amount and the resolution affect the computation time as a linear and quadruple function respectively, an experimental study was implemented to test the computation time with respect to the change of height.

In order to simplify the experiment, seven buildings were given the same height in each case. Six cases with different height ranging from 10 to 60 pixels in the shift amount were implemented with a Pentium of 200 MHz and 64 MB memory. A full-screen memory of 700x700 pixels x 3 color bands (1.47 MB) is used for the "depth distance" buffer in both "View" and "Shadow" shift.

Fig. 8 shows four examples of 3D view map with different shadow shift for the same building plan that was used in the above case study.

Fig. 9 shows the six case studies for generating 3D view maps with shadow using the polygon shift method.

Table 2 shows the computation times with respect to the change of height and the sub-programs.

As seen in the table, about 90 percent of the computation time was required for the shadow shift analysis and the integration with the view shift analysis because two full-screen buffers are to be checked.

The total computation time can be represented as a function of quadruple equation with respect to the height as shown in Fig. 10. When the polygon shift method is applied only to the generation of a 3D view map without shadow, the computation time will be less than 90 seconds in the six case studies.

Table 2. Computation times with respect to the change of height and the sub-programs. (unit : second)

| Sub Program | Case 1 H=10 | Case 2 H=20 | Case 3 H=30 | Case 4 H=40 | Case 5 H=50 | Case 6 H=60 |
|---|---|---|---|---|---|---|
| View Shift | 11.42 | 14.35 | 16.69 | 21.77 | 25.86 | 29.51 |
| Shadow Shift and Integration | 401.96 | 423.30 | 443.43 | 469.93 | 497.16 | 540.71 |
| Image output and others | 31.87 | 36.84 | 38.84 | 45.06 | 50.17 | 56.43 |
| Total | 445.25 | 474.49 | 498.96 | 536.76 | 573.20 | 626.65 |

## 7. CONCLUSIONS AND FURTHER STUDIES

A polygon shift method was proposed and demonstrated as a powerful algorithm to generate 3D view of buildings with shadow without any complicate data structure.

The concept of polygon shift including shift direction, shift amount, repetition, fore and aft polygon regions and depth distance was recognized to simplify the geometric, topologic and logical operations required for three-dimensional visualization. It can overcome the weakness of raster data structure with respect to topology by introducing the above concepts.

The polygon shift method can be widely applied to other three dimensional objects, for example, topography represented by contour lines.

Further studies should be made to extend the polygon shift method to apply to inclined roofs and perspective views. An improvement to reduce the computation time required for the shadow shift analysis and the integration with the view shift analysis has to be made.

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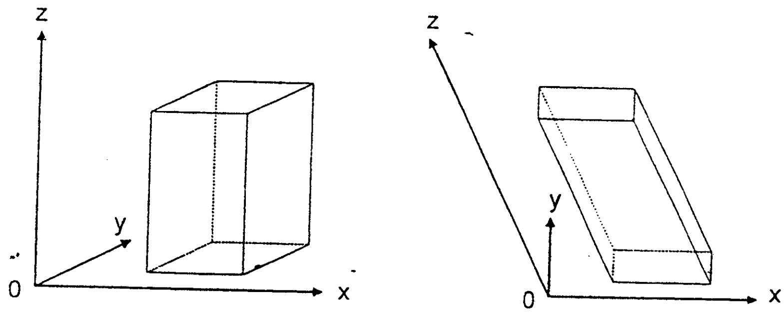
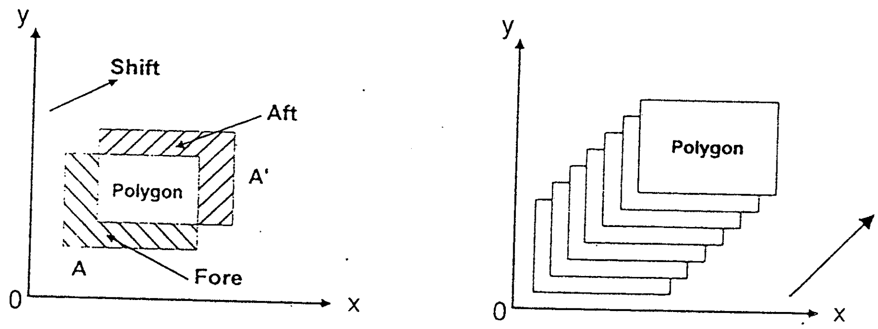



(a) Conventional 3D coordinate system with vertical z-axis and oblique xy-axes

(b) Proposed 3D coordinate system with oblique z-axis and orthogonal xy axes

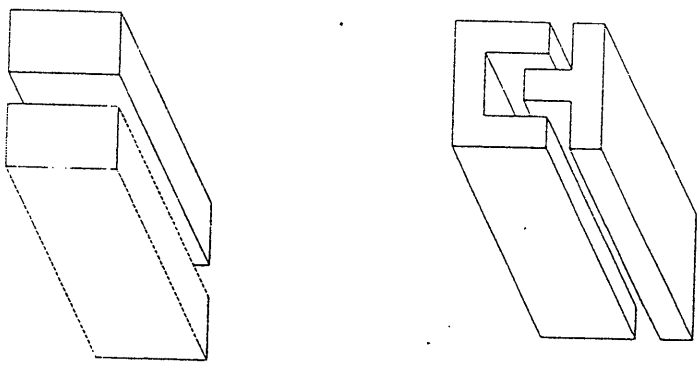
Fig. 1 Proposed 3d coordinate system for 3d view map




(a) Definition of Polygon Shift

(b) Number of Polygon Shift

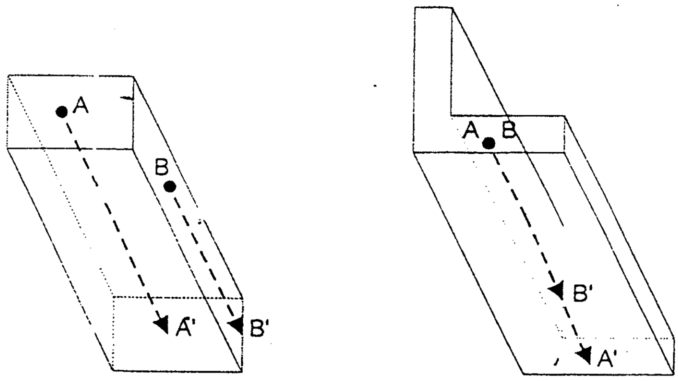
Fig.2 Concept of polygon shift method



(a) A simple case with convex shaped buildings (Closer building hides a part of farther building)

(b) A complicate case with a concave shaped building (it is difficult to judge which building is closer or farther).

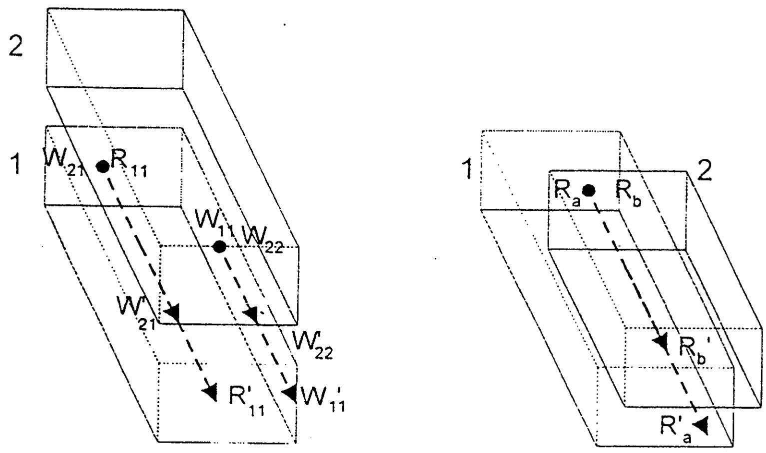
Fig. 3 Hiding and hidden buildings




(a) Depth distance of roof (Point *A*) and vertical wall (Point *B*) points

(b) Comparison of depth distance between overlapping "Fore" sides; ***A*** on the roof and ***B*** on the vertical wall (AA' > BB', then ***A*** hides ***B***)

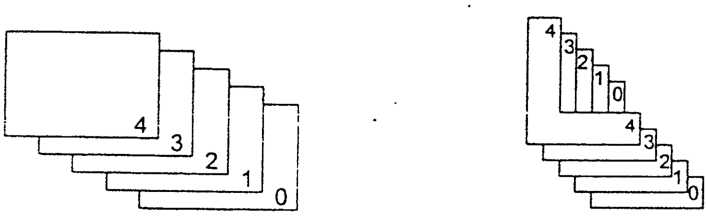
Fig. 4 Concept of depth distance




a) Overlap between roof and wall,(points $R_{11}$ and $W_{21}$) and between walls (points $W_{11}$ and $W_{22}$)

b) Overlap between roofs

Fig. 5 Hiding and hidden parts using the depth distance




a) Depth distance of a convex shaped building.

b) Depth distance of a concave shaped building

Fig. 6 Depth distance in case of polygon shift

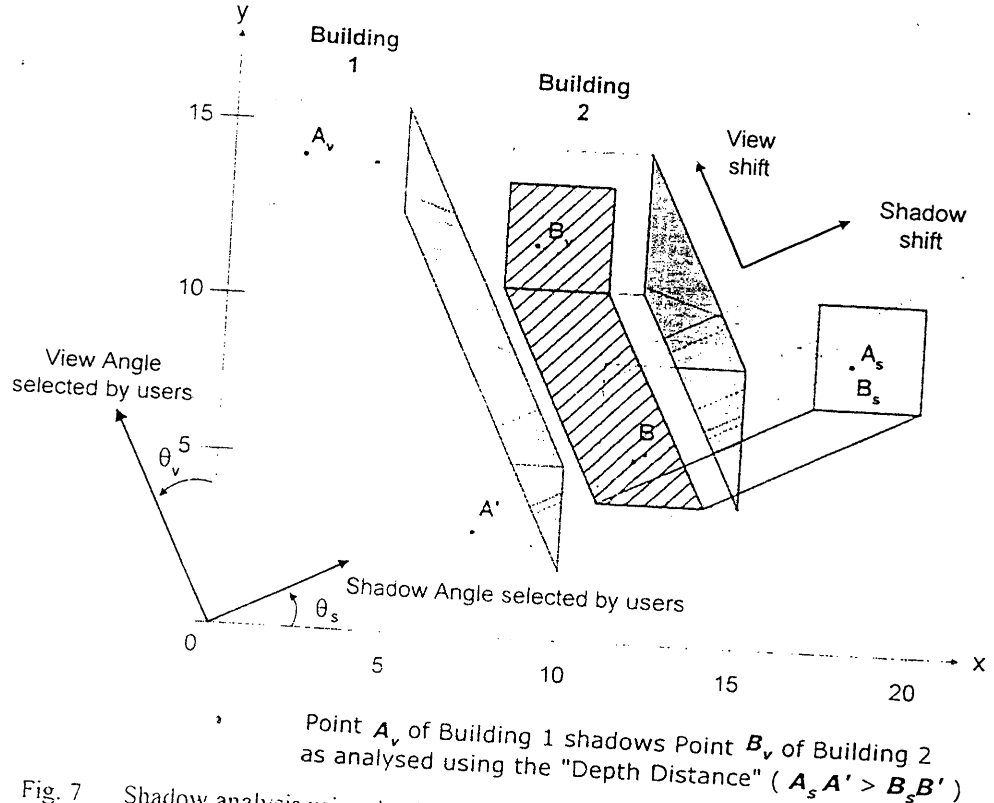



Fig. 7 Shadow analysis using the depth distance

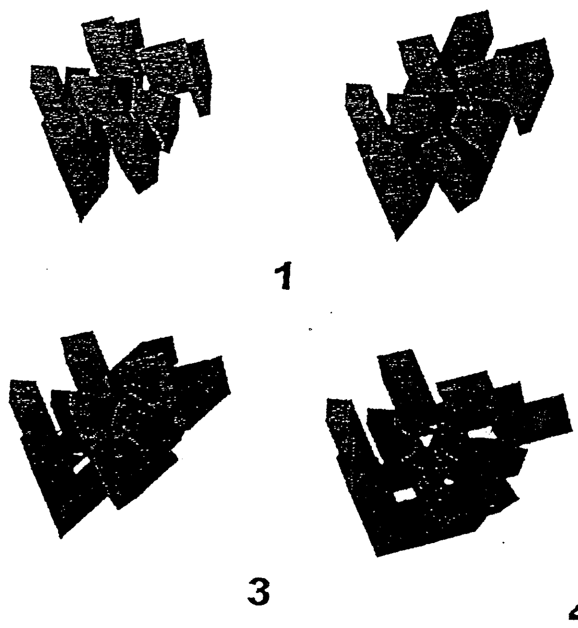



Fig.8 Various examples of 3D view map of buildings with different height and view/shadow shift direction

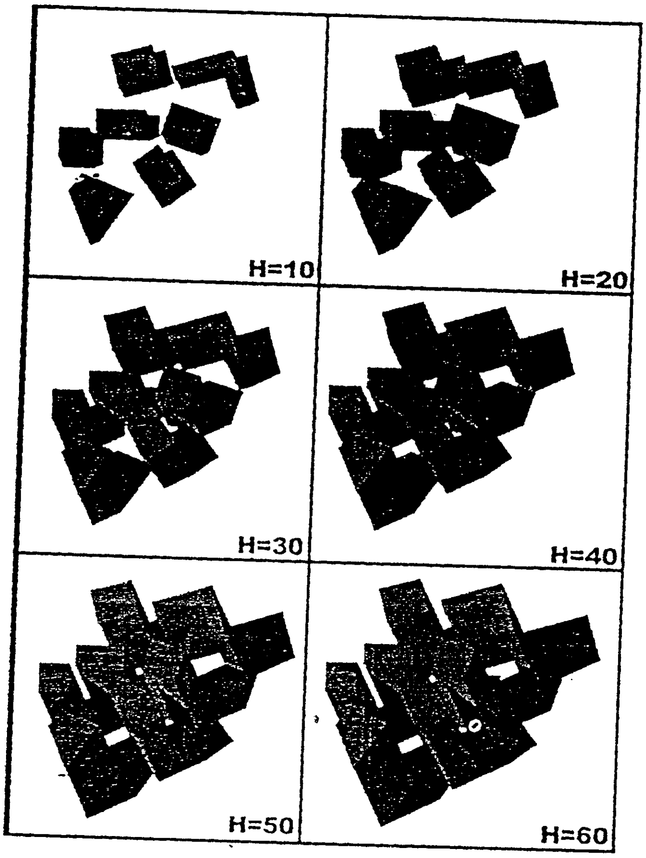



Fig. 9 Case studies for generating 3D view maps with shadow using the polygon shift method.

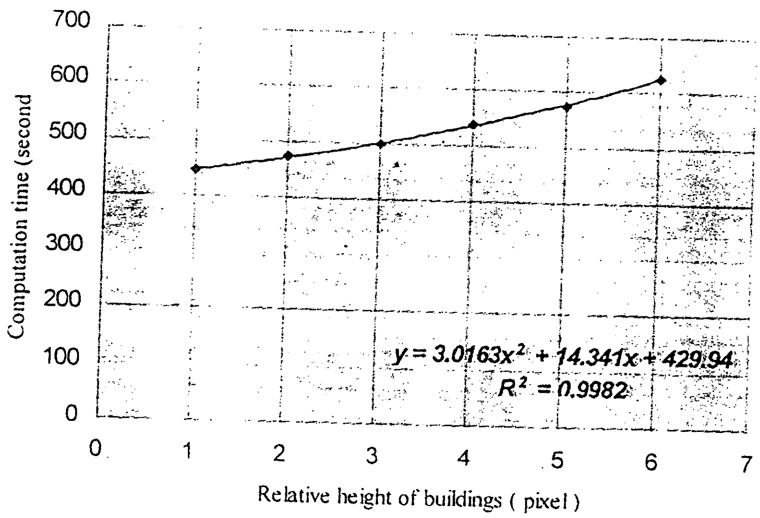



Fig 10. Computation times with respect to different height of the given buildings (see fig. 9).