

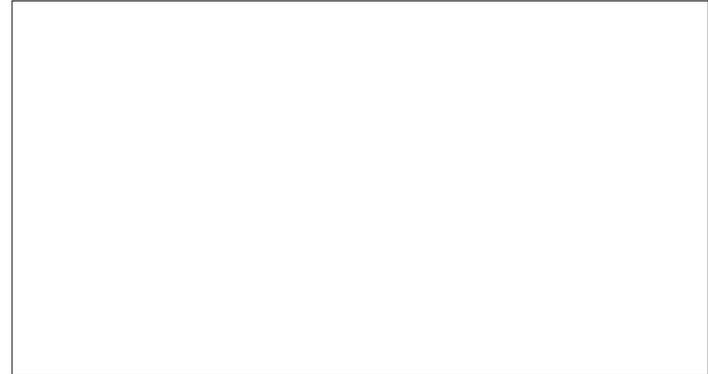
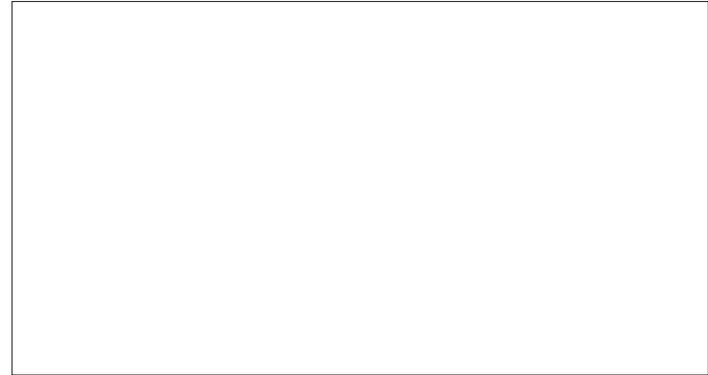
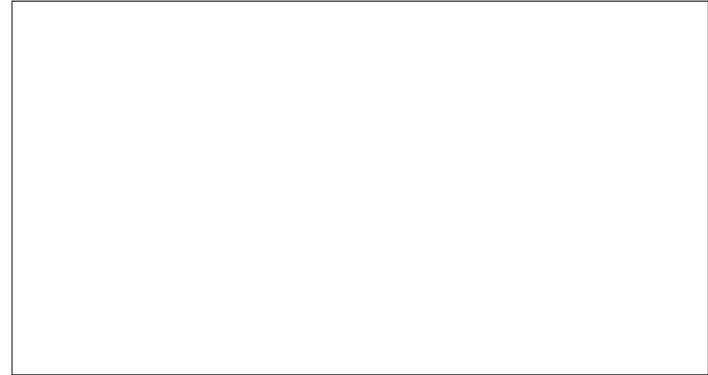
SolCAD: 3D Spatial Design Tool Tool to Generate Solar Envelope

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Abstract

In this research the concept of Solar Envelope has been used to develop a 3D Spatial Design Tool tool, SolCAD, for generating an envelope over a given site based on various design parameters. The solar envelope can be imagined as a container, whose boundaries are derived from the sun's relative motion. Buildings within this container will not overshadow their surroundings during critical periods of solar access for passive and low-energy architecture. The solar envelope is a space-time construct. Its spatial limits are defined by the parameters of land parcel size, shape, orientation, topography and latitude. It also depends on the time or the period of the time for which it is designed. Its time limits are defined by the hours of each day and the season for which solar access is provided to the land parcel (Knowles 1981). This tool intends to generate an envelope over a site of any shape, size and orientation and for different boundary and height conditions of shadow lines. It is suitable for initial stages of building design process to determine the shape of the building even before the design has been conceptualized.



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1 Introduction

Solar access has become a critical issue around the world with an increasing number of common people looking at the sun as a source of energy. Solar Access has therefore become a legitimate area of public policy. Its main objective is to regulate the conditions that will restrict or allow the neighbors to shadow one another (Knowles 1981). There should be a constant honest effort on part of the architects and planners to make sure that the building does not infringe the solar rights of adjacent properties. Pioneering efforts to solve these issues were made by Ralph L. Knowles by developing and testing the concept of solar envelope over the period 1976-1993. Solar envelope is a container within which a designed building will not cast a shadow on surrounding (Figure 1). The solar envelope is a space-time construct. The shape and the size of an envelope are defined by the geometry, orientation, topography, location of the site and its urban context. It also depends on the time or the period of the time in a day for which it is designed. Its time limits are defined by the hours of each day and the season for which solar access is provided to the land parcel (Knowles 1981).

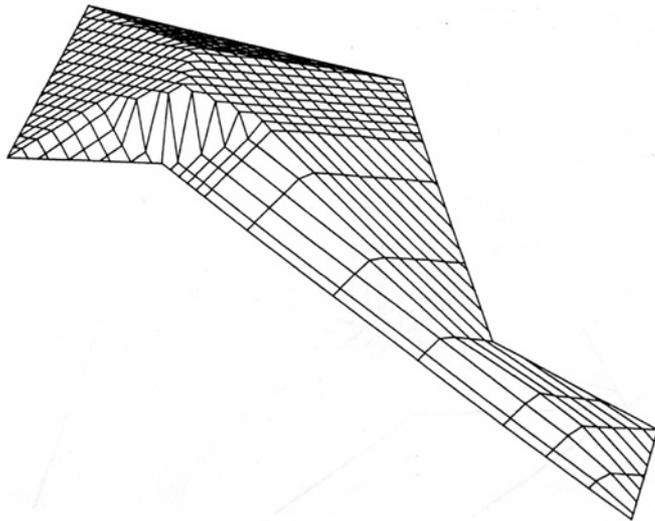


Figure 1. Solar envelope for winter solstice. (Knowles 1981)

The solar envelope helps conserve energy and improve the quality of life by guaranteeing access to sunlight during critical insolation period of a day. It can be used to give the guidelines to control building height and shape so that an appropriate amount of sunlight in the city for a particular time period can be insured. Ralph Knowles has been testing this concept in upper division design studios at the School of Architecture at the University of Southern California. The results of his research have been published in *Energy and Form*, *Solar Energy*, *Building and the Law*, and *Sun Rhythm and Form*.

In USC design studios, solar envelopes are constructed manually. All the calculations are done graphically and the results are presented using physical models. The tedious and time-consuming work involved in manual method of constructing does not leave students with enough opportunity and willingness to explore other useful issues related to solar envelopes. Even for most practicing architects, this process would be too long and time consuming to be implemented in the practice (Yeh 1992). To be effective as a design tool and a zoning instrument for urban solar-access, the solar envelope needs a computer tool for quick calculations and visualization. The most important step in this direction will be to develop a CAD tool which can not only check the validity of a given design but can also provide guidelines or suggestions to the designer for further amendments of a design.

Past attempts to develop such a tool have not been entirely successful due to their inability to include some desirable spatial and temporal constraints on the envelope's size and shape. There are various factors. The most important being the inability to generate the envelope for a complex geometrical shape and for varying shadow conditions at site boundaries. There was also a need for compatibility with the existing CAD programs so that the drawing data can be exchanged between them. Also, the past programs allowed the analysis of one set of data but failed to compare different set of data, i.e., failed to compare the solar envelope for different times of years.

2 Objective

The aim of this study is to develop a new tool that will have the ability to handle more envelope conditions without overly burdening the user and thus discouraging planning and architectural applications.

The solar envelope technique is widely accepted and acknowledged, but due to its complexity it needs an expertise in the understanding of basic geography and descriptive geometry. Moreover, the process of constructing a solar envelope manually using physical models can sometimes be very tedious and time consuming, especially for the site with a complex geometry. Furthermore, it does not allow the comparison of different time periods, based on weather and sun availability. The development of SolCAD is a step in the direction of making this process simpler for users, both experts and beginners. With the use of

SolCAD the construction of solar envelopes can be completed in a few seconds against doing it manually where it can take days and weeks to construct an accurate envelope.

The aim is to make SolCAD work for sites with complex geometry and to make it compatible with the widely used CAD tools, e.g., AutoCAD and Form_Z. It should allow users to compare the data for different time periods and for different shadow conditions. The purpose of this tool is not to undermine the importance of manual method of generating the envelope but to facilitate it with its quick calculating abilities. SolCAD by its interactivity and quick calculations will make the process of generating solar envelopes fast and accurate.

3 Existing Tools and Methods

3.1 Physical Method

So far the most commonly used method to design the envelope is by building physical models. Knowles (1981) suggested various methods to draw a solar envelope physically. He used both solid and surface geometries to generate the envelope. The physical method of generating solar envelopes uses descriptive geometry, hand calculator, protractors and physical models. Students calculate solar altitude and azimuth to physically generate the solar envelope. Physical models are built to assist the solar design. Using physical models and a sun-simulating machine, the students could actually visualize the effect of the sun's movement on a building and neighborhood (Kensek and Knowles 1997).

Researchers have also proposed and implemented a number of computer-based tools to generate a solar envelope. Arumi (1979) developed a computerized model to determine maximum permissible height of a building that does not infringe the solar rights of adjacent properties. Schiler and Yeh (1992) developed a computer program, *SolVelo*, to generate solar envelopes for flat-rectangular sites with graphical and numerical output. Kensek and Knowles (1997) explain in detail a computer tool, "CalcSolar," that has been developed at the University of Southern California, Los Angeles.

3.2 SolVelo

SolVelo is a computer-based tool to generate solar envelope developed in 1992 by Uen-Fang Patricia Yeh as her thesis for the Master of Building Science degree at USC. This program allows users to test the envelope for different latitude, times and dates, site size and orientation and neighboring site conditions such as streets, parks and the adjacent buildings. However, this tool is limited to only rectangular flat sites; gives ambiguous results for the corner conditions; and also lacks compatibility with the existing CAD tools (Schiler and Yeh 1993).

3.3 CalcSolar

One of the major steps forward in computer generated solar

envelope is CalcSolar program, which is written in AutoLisp by Karen Kensek at the University of Southern California. CalcSolar uses the geometric modeling and graphics engine of AutoCAD. It uses AutoCAD to draw sites and shadow constraints. The main advantage of this program is its interactivity and AutoCAD environment, with which most of the architects and planners are familiar. The use of AutoCAD engine has allowed this program to use its interactivity and graphical features. However, the application of this tool is also limited to rectangular sites. In spite of this shortcoming, CalcSolar tool has been a vast improvement over SolVelo and the developers have resolved some of the computing issues raised by SolVelo.

Numerous attempts have been developed to computerize the sun path diagram and shading mask protractors to analyze the shading devices. The most prominent of them were SolrPath (Haberl and McWatters) at Texas A&M University, Solar Masking Calculator and Shading Analyzer at Building Science Program, University of Southern California. But the solar envelope discussed in this paper looks into the overall shape of the building and not the parts of the buildings, e.g., fenestrations etc. It provides the designers with a form or a framework of the building to start the designing process. Its main aim is to optimize the shape of a building.

4 SolCAD

The program is written in Java programming language and has used Java3D library for graphics display. The main reason for Java as the programming language of choice is its portability. As a result it can be read and run by interpreters on many platforms including Windows 95, Windows NT, and Solaris 2.3 and later. Also, Java3D is a 3D scene-graph-based graphics programming API for the Java language. Using Java3D library developers can easily incorporate high-quality, scalable, platform-independent 3D graphics into Java.

The application has been divided into two steps. In the first step the user draws the site boundaries and shadow boundaries in AutoCAD and in the second step solar envelope is constructed using SolCAD. The mode of communication between the two steps is DXF files generated by AutoCAD.

4.1 Creating the Input File in AutoCAD

Graphical input for the application will come in the form of DXF files using AutoCAD. The site boundaries and the shadow boundaries will be drawn in two separate layers, "Site" and "Fence" respectively. The lines should be closed 3D polylines, represented by appropriate x, y and z coordinates. SolCAD assumes that on AutoCAD screen the north will always point up. Therefore, the site has to be drawn relative to screen's north direction. Once the site boundaries and shadow boundaries are created, the drawing is saved as DXF file.

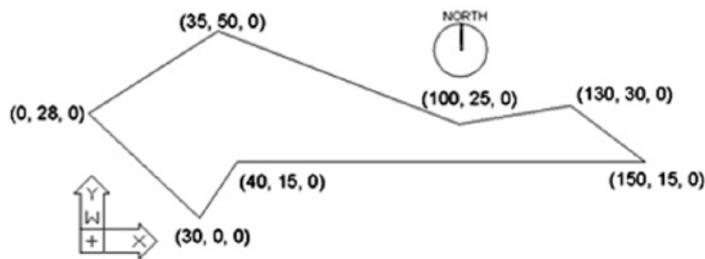


Figure 2: Sample site drawn in AutoCAD. (Knowles 1981)

4.2 Inputs in SolCAD

SolCAD allows the user to construct two types of envelopes, *Single Day Envelope* and *Composite Envelope*. The single day envelope allows users to generate the envelope for a given time period in a day, e.g., envelope for the time period between 9:00AM and 3:00PM on 21st September. The composite envelope allows the generation of optimized solar envelope for different time periods in a day and also for different times periods in a year, e.g., if users want to see the optimized solar envelope for the entire year, the composite envelope will calculate the envelopes for summer solstice, equinox and winter solstice and will give the optimized result.

To construct Single Day Envelope, users need to select the Select “*Single Day Envelope*” menu item from the control menu. In the dialog box that appears (Figure 3), the desired DXF file is chosen. The variables for the input are month, day, cut-off times, latitude, and grid size. Month represents the month for which the envelope is desired and day represents the day in that month. The cut-off time is a set of times that defines the start and the end of a time period, where start time represents the time of a day from which the envelope is valid and end time represents the time until the envelope remains valid for that day. Grid size decides the density of the mesh representing the envelope, i.e., the distance between the grid points. Maximum permissible height is the height a structure can have in the given area or on the given site as per laws. The north latitudes are given positive values while the south latitudes are given negative values.

The construction of the composite envelope is relatively simpler. The main inputs are the two DXF files having geometric information about solar envelope for two different conditions (Figure 5). Once the program is executed, it compares the information in both the files and calculates the optimized result. The two DXF files, which are used as input, are basically single day envelopes constructed for different time periods or different days or both. One of the highlights of this method is that we can compare and optimize the envelopes for any number of cases simply by first constructing single day envelopes for individual cases and then comparing them with one another.

4.3 Algorithm

There are two approaches for constructing solar envelopes: solid modeling and surface modeling. SolCAD uses the surface geometry method to construct the envelope. Using surface geometry every object is identified to be composed of a number of planes or lines. As a result, clipping is faster and more accurate in surfaces than in solids.

The main idea is to define a cut-off plane for each edge at a regular interval. The edges of each of these planes are defined by the lines drawn from sun’s position to the start and the end points of an edge of the site. These cut-off planes are then used for further clipping operations.

The site is divided into a grid based on the grid size provided by the user (Figure 7). Vertical lines are drawn from each grid intersection points and also from the intersection points of grid lines and edges. These vertical lines are clipped for each plane separately and the intersection of each line with the plane is recorded every time clipping is performed on it. Each vertical line should have the minimum height at the end of the calculations in order to optimize the envelope.

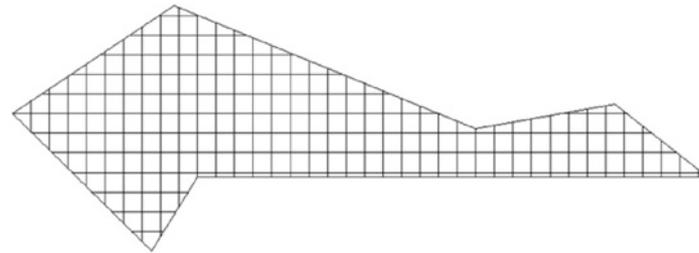


Figure 7: Grid layout on the site

SolCAD uses parametric equations for determining the planar surfaces. The parametric equation of planar surface defines infinite plane, which gives ambiguous results because if a plane is infinite then every line will have an intersection with it. The first check determines if the grid intersection point lies within the plane defined by the edge and sun’s position, projected on the ground, i.e. if $z=0$. If the point is within the plane, then the clipping is performed on the vertical line at that point. In the second check, height of the vertical line (z -value of the end point of the line), which is obtained after clipping, is compared with height that is currently stored. If the new height is found to be

less than the current height then it replaces the current height. Thus, at the end we have a set of vertical lines at each grid intersection point with minimum height (z-value).

At the end, the final shape is set by the shortest height attained for each vertical line. Endpoints of these lines can be joined with each other to draw the envelope (Figure 4-11). The accuracy of the envelope depends on the fineness of the grid. A greater degree of precision can be achieved by making the grid dense.

4.4 Output

The output is in the form of a sloping mesh, which defines the solar envelope. Each point on the mesh gives the height or the elevation of the envelope at the corresponding point on the ground. This mesh is connected to edges/boundaries of the site at the height derived from the calculation. The end points of these are then joined to form a mesh. The user has an option to view the mesh in SolCAD or to save the file in DXF format and view it in AutoCAD (Figure 8) (Figure 9) (Figure 10).

4.5 Test

The tool was tested for various site conditions, shadow conditions as well as for various temporal conditions. Different shadow conditions were taken into account. The possible shadow conditions that emerged were:

- 1) No shadow should fall beyond the site boundaries, i.e. shadow height is zero on boundaries.
 - 2) Shadows of certain height will fall either on neighboring properties or on streets or on site boundaries. The heights for the shadows can be provided by placing shadow lines at appropriate positions (section 4.1).
 - 3) Shadows of varying heights fall on the neighboring properties in the form of a pattern.
- The sites' conditions were mainly related to the shape and the topology of the sites. The conditions tested were:
- 4) The sites with irregular shapes (both convex and concave polygonal shapes).
 - 5) The sites with generalized slopes.
 - 6) Width of the surrounding street.
 - 7) A courtyard inside the proposed building on the site.
- The temporal conditions were tested for 34° N latitude (Los Angeles).
- 8) Three different days in the year summer solstice (21st June), Equinox (21st September), winter solstice (21st December). The days can vary with the place and the discretion of the users.
 - 9) The cut-off time was taken to be 9:00AM-3:00PM for June and September, and 10:00AM-2:00PM for December.

5 Future Improvements

There are some limitations with the current version of SolCAD. The current version is not completely a CAD tool yet. It doesn't allow the user to draw the site and boundary inside the program and depends on the input in the form of DXF files. Efforts are

being made to enhance the interactivity of the program, which include providing drawing and editing capabilities inside the tool, a better user interface where the user can interactively select the options or the parameters, e.g., providing an interactive world map for selecting the latitudes of the location of the site. The current version recognizes the continuous slope in one



Figure 3. Dialog Box for Single Day Envelope

direction. It will be improved to read more complex topography. The program can also be improved to share the data with related programs like DOE, SOLSHADE and SHADOW. This will widen the scope of its application and will give the user more options. Not only will it increase the usability of the program but will also make many tasks that have become very complicated due to the use of DXF files because many programs have limited capabilities with DXF format.

To widen the application of the tool, it will be upgraded to support the GIS systems. This will extend its utility to an urban design and city planning level.

6 Conclusion

The solar envelope not only protects the solar rights of adjacent buildings but also determines the shape of the building. It helps in designing environmentally responsive buildings to improve living conditions.

The objective of SolCAD is accurate calculation and quick generation of solar envelopes. It is a 3D Spatial Design Tool

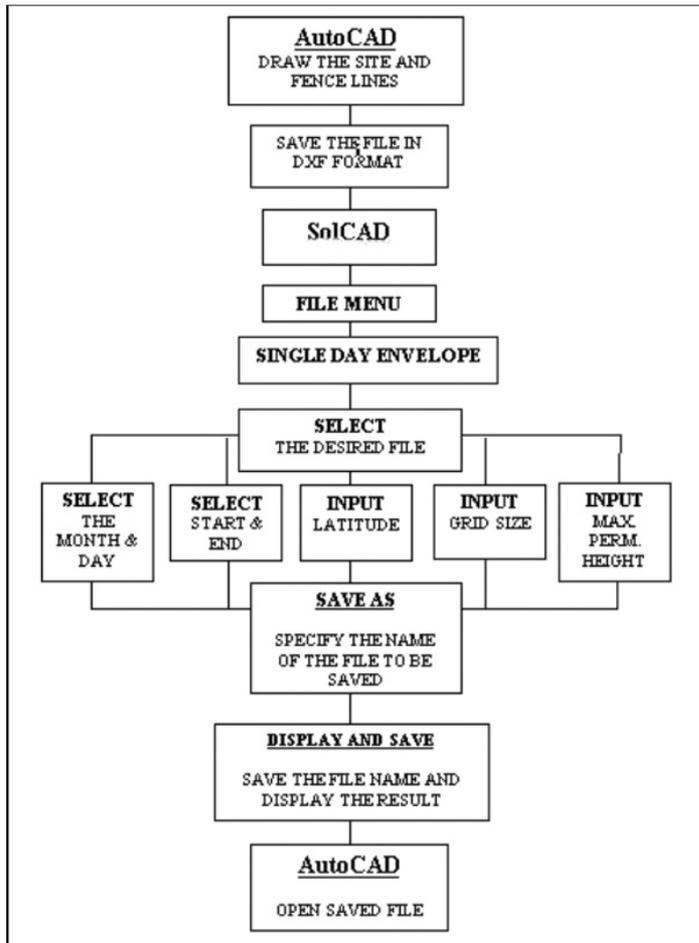


Figure 4: Flow chart for single day envelope

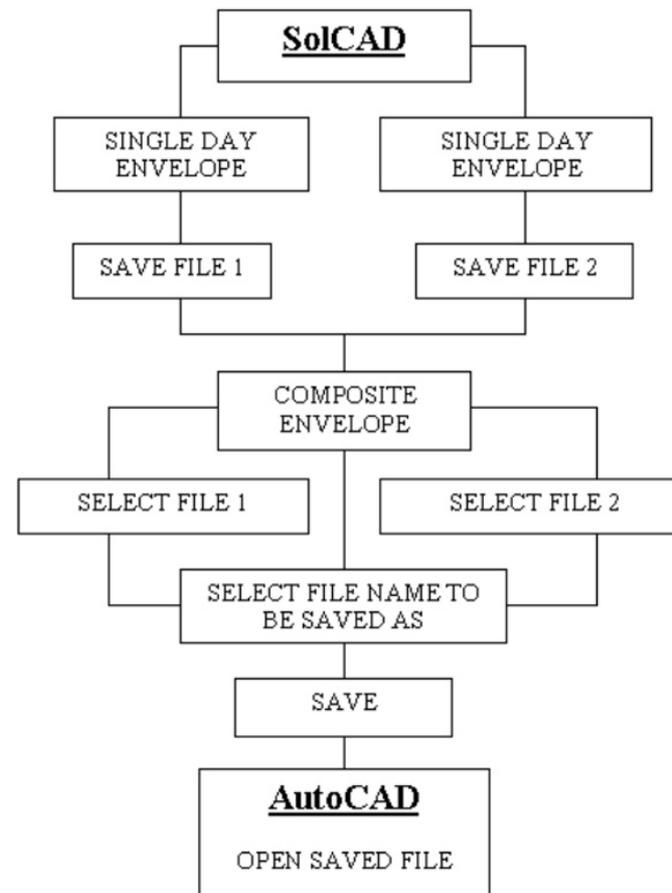


Figure 6: Flow chart for composite envelope

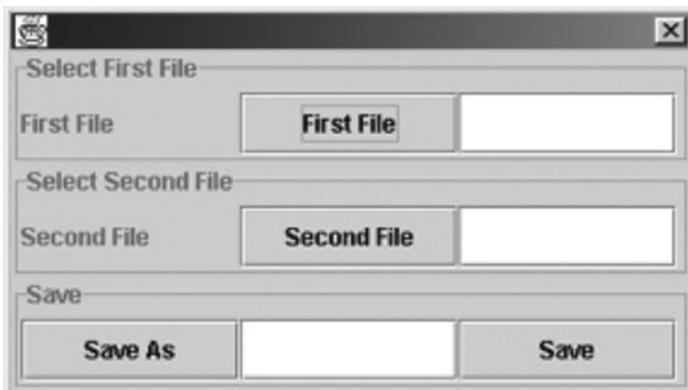


Figure 5: Dialog Box for Composite Envelope

tool for architects, designers, building services engineers and planners. It is suitable for initial stages of building design process to determine the shape of the building even before the design has been conceptualized. It provides design as well as the zoning guidelines in terms of an envelope around the site so that if a building conforms to the shape of solar envelope or remains within the envelope, it will not infringe on the solar rights of the neighboring properties.

SolCAD, has vastly improved upon the shortcomings of earlier tools. It has the ability to read and write DXF files. This has made the tool compatible with popular CAD tools such as AutoCAD and Form_Z. It can analyze sites with different polygonal shapes. It can analyze sites with generalized slopes. SolCAD can read

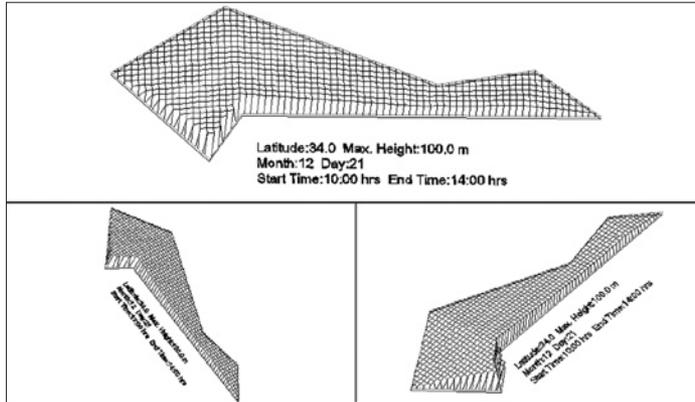


Figure 8. Single day envelope on 21st December

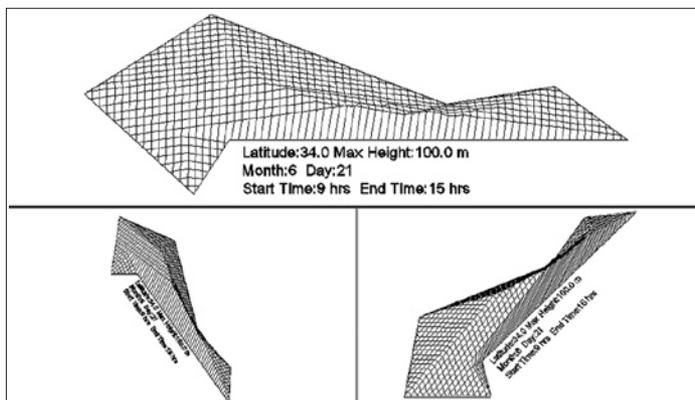


Figure 9. Single day envelope on 21st September

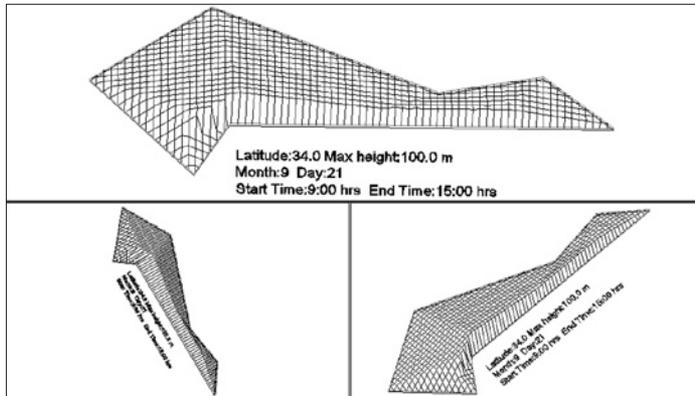


Figure 10. Single day envelope on 21st June

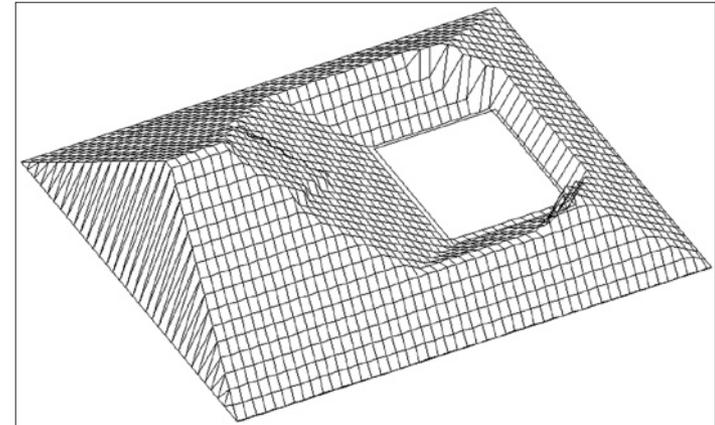


Figure 11. Solar envelope for building, having a courtyard, on a site

the shadow constraints with varying shadow-height conditions inside the site boundaries, over the site boundaries and outside the site-boundaries. It can very well recognize the courtyards within a building. It can also recognize the outlines of shadow-patterns on adjacent properties. Not only can we analyze the solar-envelope for a single day as in the past tools but we can also compare the solar-envelopes between different time periods to get an optimized envelope, called a composite envelope. The program has a user friendly Graphical User Interface (GUI) that allows easy input and shows the results as three-dimensional graphical output. SolCAD takes much lesser time than other similar tools to complete the task of same complexity.

7 Acknowledgements

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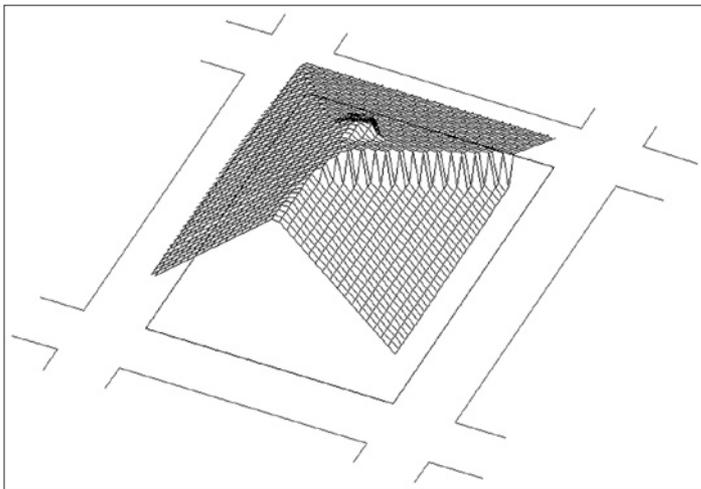


Figure 12. No shadow on neighboring properties separated by 15 m

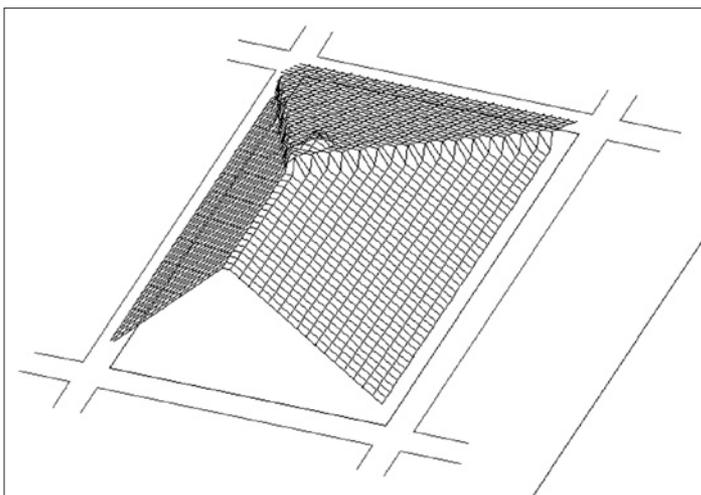


Figure 13. Envelope changes if the distance between adjacent properties changes

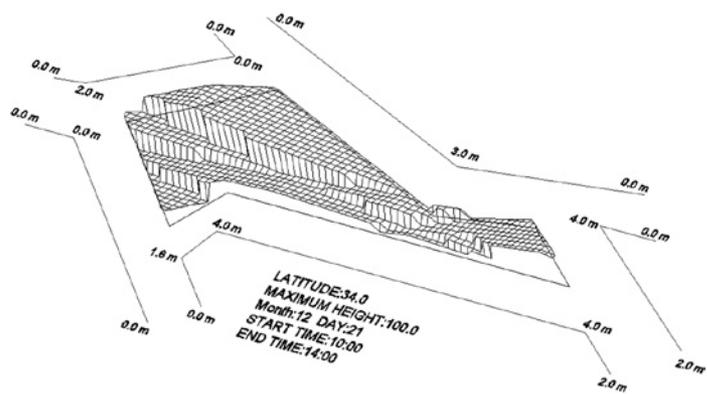


Figure 14: Envelope for shadow lines of varying height on adjacent properties

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